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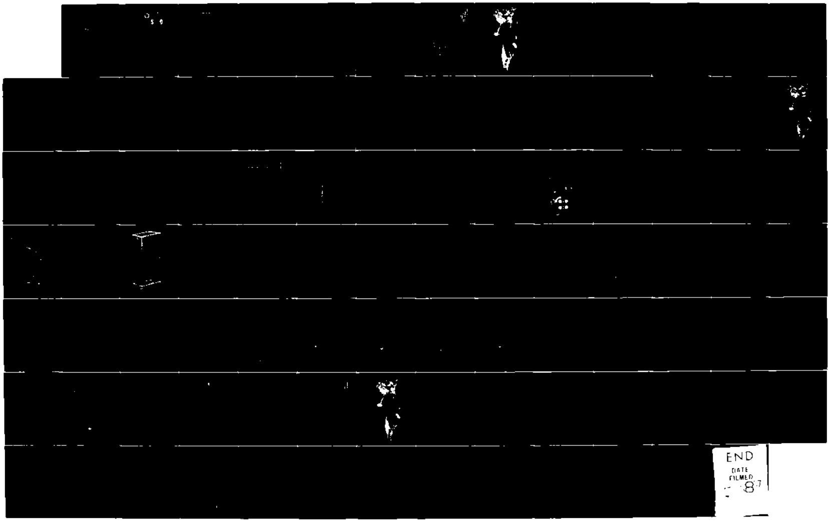

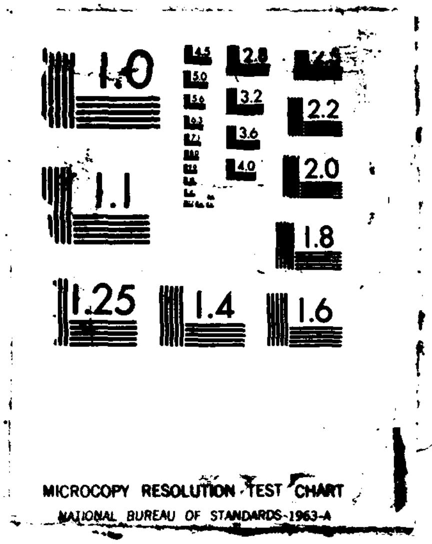
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FINAL REPORT

PERIOD OF PERFORMANCE
29 SEPTEMBER 1986 TO 31 APRIL 1987

TITLE:
A NOVEL CONCEPT FOR THE RAPID DEPLOYMENT OF ELECTRIC POWER CABLES

PREPARED FOR

U.S. ARMY BELVOIR
RESEARCH, DEVELOPMENT & ENGINEERING CENTER
FORT BELVOIR, VIRGINIA

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PREPARED BY

UNIVERSITY RESEARCH ENGINEERS & ASSOCIATES, INC.
P.O. BOX #5398
1554 SWALLOW WAY
HERCULES, CA 94547-5398

&

72 YALE STREET
WINCHESTER, MA 01890

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The report covers the research & analysis required to establish the feasibility of a concept to design and demonstrate a system for rapidly deploying and retrieving electric power cables by launching the cables through the air. The TOW Missile is the optimum deployment vehicle for transporting one end of the cable toward the tactical position that requires power. The approach effectively neutralizes both man-made and naturally occurring deployment obstacles, e.g. nuclear, biological

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chemical environment, combat zone, impassable topography (deep ravine, steep cliff, etc.), open hostile areas (marshes, lakes and rivers). The deployment range is estimated to be 500 to 1000 ft. The retrieval can be accomplished by a robotic device that automatically cleans, disconnects, coils, packages and covers fifty foot lengths of cable.

EXECUTIVE SUMMARY

INTRODUCTION

The executive summary is partitioned in two segments; Part I, Summary, Conclusions & Recommendations of the Phase I Feasibility Study relating to the Novel Concept For The Rapid Deployment of Electric Power Cables and Part II, a Summary, Evaluation and Status of Alternative Power Transmission Opportunities, including both dedicated (wires & cables) and nondedicated (wireless) mediums.

The two approaches (dedicated & nondedicated) for transmitting power should be considered complementary as compared to competing systems because each can play an important role in future rapid deployment applications. The wireless approaches, generally considered to be either microwave or laser, are envisioned by most experts to be limited to "Line of Sight" (LOS) applications. This means, of course, that the <u>transmitter</u> (or power source) and the <u>receiver</u> must be located in a straight line with no physical interruptions between. This LOS requirement can be a serious limitation in rapid deployment of electric power that does not encumber the cable approach. A number of power transmission scenarios can be developed where the two approaches, if coupled, could provide the Army with a potent system for supplying power to remote tactical locations.

The recent announcements of the results from on-going research in both super conductivity and intercalated graphite compounds suggest that these emerging technologies will have a positive impact on the Army's goal for rapid, flexible, mobile, reliable and survivable methods of deploying power. Some of the newer conductor materials, for example, have the potential to provide excellent conductivity and beneficial weight-to-strength ratios. These characteristics, when fully developed, will enhance the utility of the deployment concept discussed herein.

PART I

A BRIEF DESCRIPTION OF THE RAPID DEPLOYMENT OF ELECTRIC POWER CABLES (RDEC) & ROBOTIC CABLE RETRIEVAL (RCR) CONCEPT

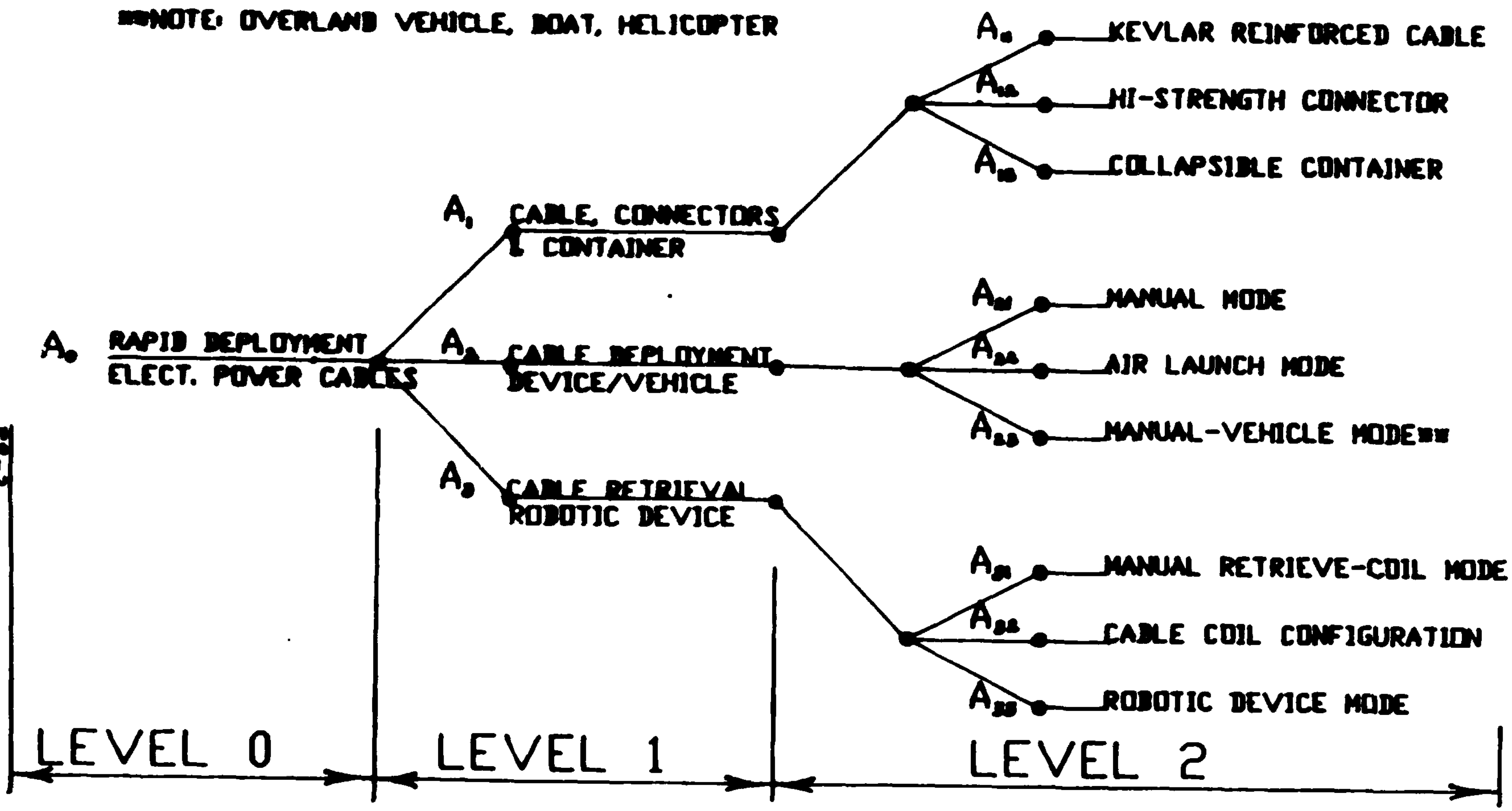
SUMMARY

The concept for the rapid deployment/retrieval of electric power cables is an integrated system that is composed of several discrete components arranged in a hierarchal format (tree) for organization and discussion purposes (Figure ES-1). While the RDEC/RCR system concept deals with both deployment and retrieval of electric power cables, the major emphasis (high priority) is on the rapid and flexible deployment component. The RDEC concept is **flexible** in that it can accomodate deployment from conventional vehicles such as jeep, truck, aircraft, boat or manual methods. Each of the above methods, however, could require several hours to connect the power <u>source</u> to a tactical position <u>user</u>. Since this amount of time delay might be unacceptable under certain combat conditions, the **air launch concept** (Figure ES-2) was established to promote **very rapid** deployment, i.e., the deployment time could be reduced to a matter of a few minutes.

A BRIEF OPERATING DESCTIPTION OF THE RDEC/RCR CONCEPT

The **Power Cable Air Launch Mode** using a system that is currently in inventory is a **keystone approach** of UREA's concept. Figure ES-2 shows an artist's rendering of a tripod mounted TOW* missile unit as it might be used to rapidly and accurately deploy a power cable. Detailed technical discussions with the TOW System Program Office (see pages 31 & 32 of this report for additional details) indicate that it is **highly probable that this system could be successfuly utilized as the air launch component (Level-2) of the concept.**

*Note: Tube Launched, Optically Tracked, Wire Guided Command Link Missile System.



UNIVERSITY RESEARCH ENGINEERS AND ASSOCIATES, INC.
HERCULES, CA 94547
DESIGNER: TOM CALLAHAN
APPROVAL: Tom Callahan
S-DATE: / / C-DATE: / /
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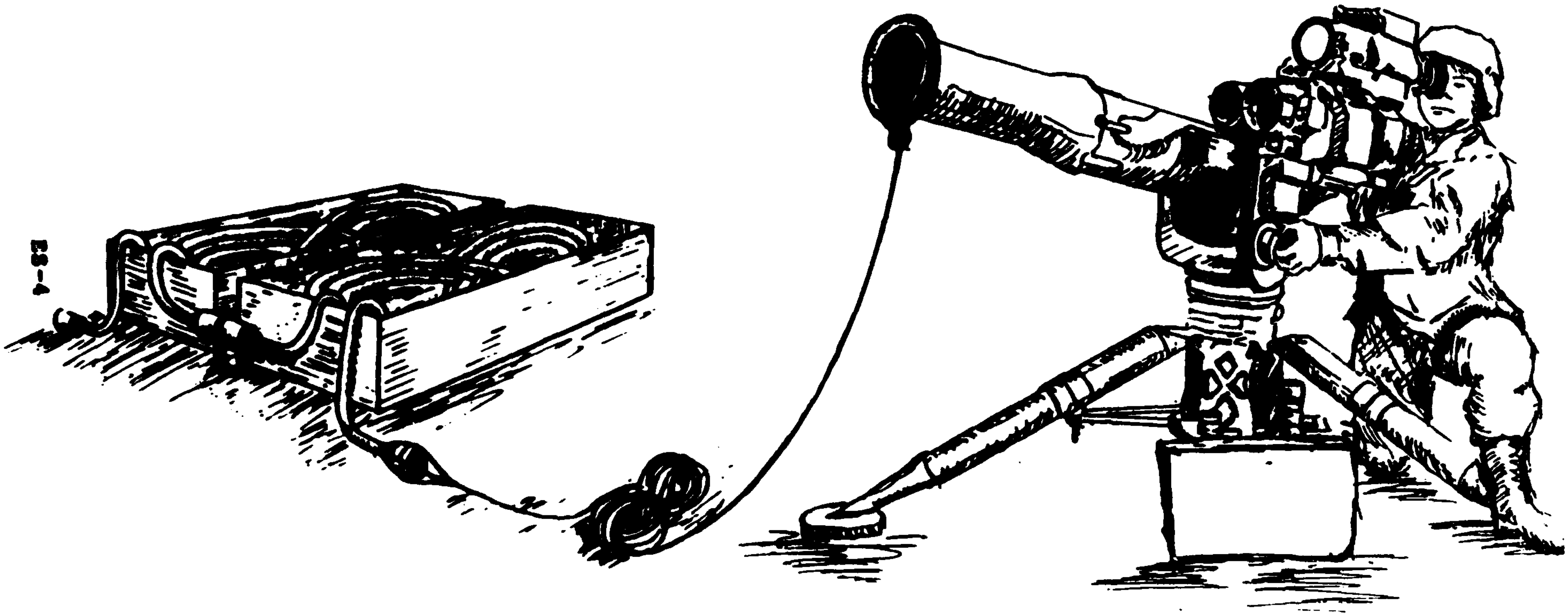
RDEC FUNCTIONAL COMPONENTS GROUPING HIERARCHY

FIGURE ES-1



TOW MISSILE CABLE AIR LAUNCH
SKETCH

FIGURE ES-2

The cable deployment team would merely connect the appropriate number of cables required to span the distance between power source and user. The power user end (PUE) of the cable would be attached to the TOW missile umbilical cord (Figure ES-2). The TOW missile would be launched and carry the light weight umbilical for the first few seconds of flight. At that point the missile will have reached full power and begin to assume the load (weight & mass inertia) of the electric cable. Since the TOW is a wire guided system with a reputation for extreme accuracy, it is anticipated that the cable can be delivered to a user located within a 1000 foot range with good accuracy (15 to 25 yds.). When the PUE & the Power Panel End (PPE) connections are made the deployment process is complete.

The retreival process (RCR) begins by disconnecting the cable at both the user and source ends of the cable. The PPE of the cable is manually loaded into the robotic device and tension is applied to pull the cable towards the source. The device would be designed to clean the cable if it were exposed to a Nuclear, Biological, or Chemical (NBC) environment. The cleaning would take place before the cable could contaminate any of the retrieval or packaging mechanism. The device would also disconnect (in-line) coil, package and cover the cable for storage. In addition, the capability to sense and distinguish the normal retrieval resistance from the loads developed by some obstruction would be incorporated into the mechanism and controls. Another important feature of the concept is the ability to develop some violent oscillations in the cable if it is needed to free it from an obstruction.

GENERAL CONCLUSIONS & DEVELOPMENT RISK ESTIMATE

The central conclusion of the Phase I study is that the original deployment (RDEC) and retrieval (RCR) concept, with minor modifications, is feasible. The deployment schematic shown in Figure ES-3 indicates some of the obstacles that can be overcome by this approach. In addition, there are multiple mechanism design approach options and deployment method options available to Ft. Belvoir that will enhance the opportunity to optimize the

prototype rapid deployment/retrieval system design and demonstration.

The detailed RDEC/RCR system concept, as described in the Phase I proposal and in Section 3.0 of this report, employs some nine functional components (Figure ES-1). Thus, the concept feasibility and development risks are dependent on estimates that include a composite picture of all nine components performing as predicted. In addition, several of the more important system components are supported by both a primary and at least one alternate (back-up) concept. Therefore, based on the primary conceptual components only, **the development risks are estimated to be low to moderate.**

The detailed information and technical data required to support that conclusion are documented and reviewed in Section 3.0, Technical Discussion and Appendix A, A Computer Model of the Cable Air Launch Component. However, a brief discussion of the higher priority Level 2 Functional Components is provided in the section: Phase II Development Program Implementaion Recommendations below.

PHASE II DEVELOPMENT PROGRAM, IMPLEMENTATION RECOMMENDATIONS

The design and development of both the RDEC & RCR system components results in a significant size R&D program. Figure ES-1 shows three Level-1 components; i.e., A_1 Cables, Connector & Container; A_2 Cable Deployment Device/Vehicle and A_3 Cable Retrieval Robotic Device. The general concensus both at Fort Belvoir and UREA is that the cables, the connectors and the deployment (RDEC) component have a much higher implementation & demonstration priority than either the container or the retrieval (RCR) component. It is also true that the RCR component design activity would normally be scheduled after the completion of many of the RDEC components. This suggests that a commitment to the RCR design program need not be made until after the completion of the RDEC component.

In addition, the design of the A_3 robotic component would include a complicated mechanical device, a special purpose computer (requiring intensive hardware & software development), dedicated sensors, and a telecommunication device. Thus, it is clear that the lower priority level-1 system component is also the most expensive element of the total development effort and funding will not be needed until the RDEC component is in place and operational.

Therefore, the Phase II Design, Development and Demonstration Program has been organized to reflect both the development priorities and the logical developmental effort as noted above. The hierarchal format or tree structure that reflects the proposed Phase II program implementation and control strategy is shown in Figure ES-4.

The **Phase II Implementation Recommendations** are:

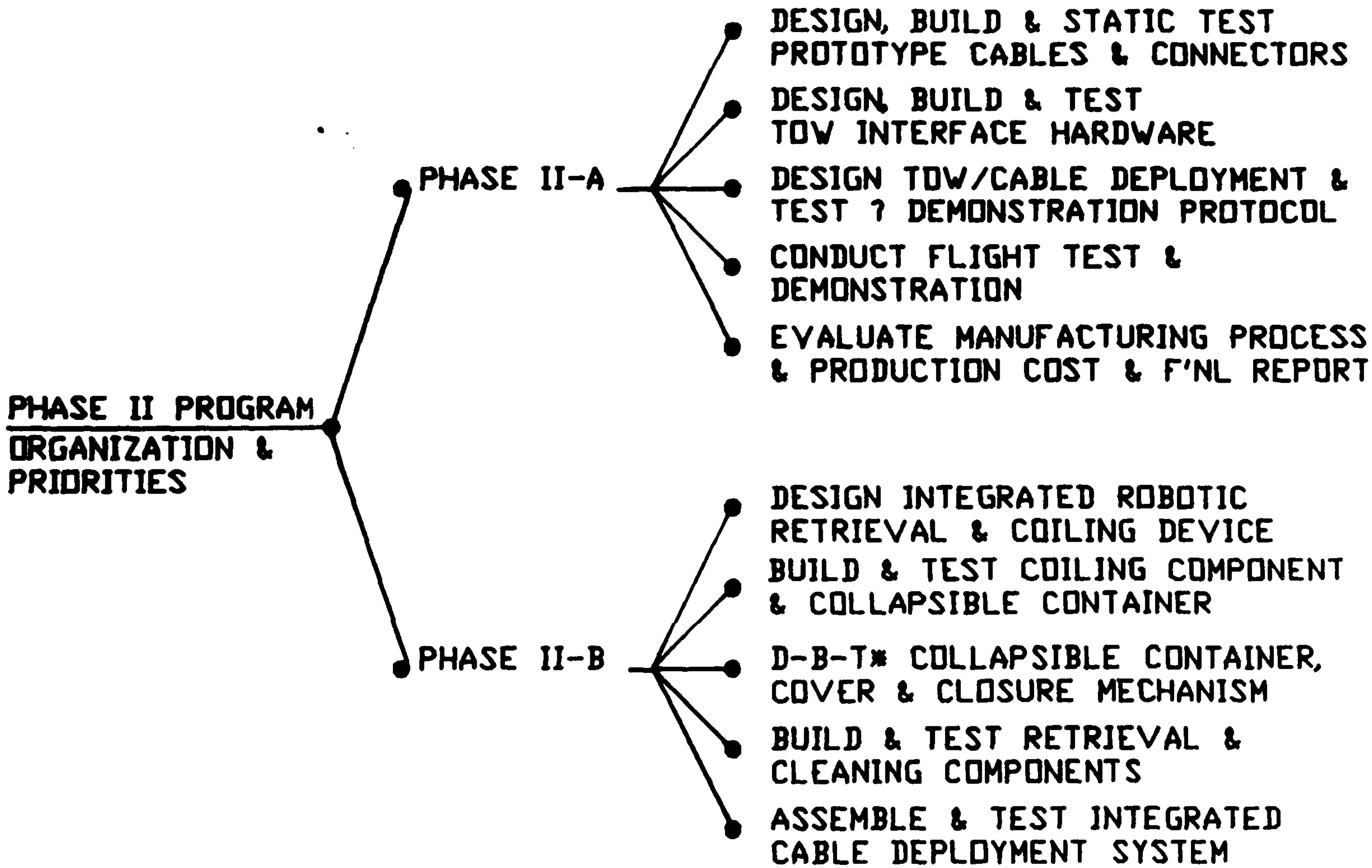
1.0 **Implement the Phase II-A Program** as outlined in Figure ES-4

2.0 **Evaluate the Phase II-A Demonstration** and the potential long range benefits of this power cable deployment method as well as its logistics burden . . . if the results warrant;

3.0 **Implement the Phase II-B Program** as outlined in Figure ES-4

TECHNICAL SYNOPSIS OF THE HIGH PRIORITY LEVEL-2 COMPONENTS

A_{11} **KEVLAR REINFORCED CABLE** A successful cable design is fundamental to the RDEC concept. Early in the program, preliminary discussions with DuPont indicated that they believed the air launch application using a Kevlar reinforced #6AWG power cable was feasible. Based on computer model estimates of the cable launch load parameters, the cable designers (from two separate companies) judged that a cable, reinforced with a braided Kevlar (aramid fiber) prior to vulcanizing a neoprene outer jacket, could be developed. The resulting cable would not only survive in an air launch environment but have a life cycle better than conventional cable when exposed to the crushing loads from vehicular traffic, etc.



PHASE II: PROGRAM IMPLEMENTATION & MANAGEMENT CONTROL STRATEGY
FIGURE ES-4

A_{12} HI-STRENGTH CABLE CONNECTOR

A preliminary sketch of a unique cable connector concept was suggested in the original proposal (Breech Lock Type Cable Connector). It appears that this design, with minor modifications, will satisfy the needs of the program. A second connector design, an improvement over the breech lock, is under evaluation and will be detailed early in Phase II. The standard commercial connector, which was considered for this application, does not satisfy Fort Belvoir's requirements for:

(1) easy attachment

(2) lighter weight

(3) abrasion resistance

(4) lower cost

It is likely that some synthesis of these designs will emerge as the device that will meet the program needs and other longer range manufacturing considerations and cost.

An evaluation of the manufacturing SOA of both the cable and the connectors suggest that current commercial practice is delivering product below its potential for producing higher quality cables at lower cost. In addition, the design approach has been so standardized that there is little opportunity for innovation. Therefore, early in Phase II, the feasibility of integrating both the connector and the cable into one single device will be established. The single integrated device's performance potential will be compared to the traditional cable & connector assembly.

A_{22} AIR LAUNCH MODE

In deference to both cost and logistics burden, the primary concept should employ a device that is already in the DOD inventory, if possible. A number of such devices in the Army inventory were investigated, e.g., TOW, STINGER, DRAGON, 155mm HOWITZER, and the MK 19-3, 40mm GRENADE LAUNCHER to name a few. The initial possibilities were narrowed early in the Phase I program to the **TOW Missile System** (Figure ES-2).

The early air launch analysis performed at Tufts University indicated that a controlled thrust device such as a missile would be more appropriate for the concept than a high initial impulse

type device such as the grenade launcher, howitzer or mortar.

TOW ATTRIBUTES

An evaluation of the attributes of TOW indicated that the system offers substantial deployment advantages over other candidate systems. For example, it is widely used, and thus readily available, because it is an effective and reliable weapon system. The system has been up-graded several times which indicates that its useful life cycle has been extended many years into the future. One of the more recent up-grades was the addition of a forward-looking infrared sight to provide the capability to see targets through darkness, haze and smoke, a distinct advantage if it were used to deploy power cables. The missile is deployed as a part of many different weapons systems, e.g., a single TOW mounted on a tripod for use by the infantry (Figure 3.5-A), 2 to 4 TOW's mounted on the side of a helicopter (re: AH-IS COBRA), 12 TOW's mounted on the Improved TOW Vehicle, a single TOW mounted on a CUCV or HMMWV. TOW is also used on the Bradley Fighting Vehicle.

After a review of the concept and operating parameters, the TOW System Program Office (SPO) was optimistic that the TOW could be used as a cable deployment device. The SPO strongly suggested that RDEC designers should work closely with TOW engineers to assure that the required attachment of the cable to the missile was designed such that any disturbance to the in-flight characteristics is minimized. This approach to a cooperative design effort would be enthusiastically embraced by UREA. Phase II development testing and demonstrations at the MICOM missile test site can be arranged through Ft. Belvoir. In addition, the SPO offered helpful design suggestions relating to the interface between the missile, the launch tube and the umbilical cord (Figure ES-2).

PART II

INTRODUCTION

In any development program it is incumbent on the system designer to not only evaluate the feasibility of the short term R&D program but also to look as far into the future as possible and estimate the long range utility of the system. The estimate must be based on the practicality of emerging technologies; the point in time they can be expected to intersect the schedule, and the impact that they may have on the program. In keeping with that responsibility, UREA reexamined the electrical transmission mediums. The mechanism for transmitting the power from one point to another can be accomplished either by a dedicated device (conduit/conductor) or a nondedicated medium (atmosphere, ground, or water). While other sections of this report will examine the traditional dedicated medium of copper and aluminum conductors, Part II deals with the on-going exploratory research on both dedicated and nondedicated mediums for power transmission. The emerging technologies of interest are:

a) Intercalated Graphite Compounds
b) Super Conductors
c) Microwave Power Transmission
d) LASER Power Transmission

INTERCALATED GRAPHITE MATERIALS

The traditional conductor materials (copper and aluminum) have some attractive functional attributes and are often compared on a conductivity/weight or strength/weight basis. In the R&D program plan for cable core materials recommended in the MERADCOM document (July 1978) an anisotropic, graphite, intercalation compound with better conductivity and lower specific gravity than either copper or aluminum was briefly noted. **The potential utility of this or similar compounds must be established because of the possibility of significant performance improvement** to the Air **Launch Concept**. The significance of this material developmemt has been explored further as part of UREA's effort to establish its relevance and impact on the proposed concept and the future of

this development effort.

The state of the R&D programs for the intercalated graphite material was explored and evaluated by both UREA and the cable manufacturer on a cooperative basis. It is interesting that two diametrically opposite opinions resulted from this evaluation.

The cable manufacturer believes that current research is not meaningful to the cable manufacturing industry with the possible exception of reinforced aluminum wire.

UREA, on the other hand, believes that the research being conducted at Massachussetts Institute of Technology and the University of Pennsylvania will have a significant impact on power transmission and the cable manufacturing industry within five years (circa 1990). The prevailing opinion appears to be that the technology has emerged from the labratory as a practical alternative to the traditional conductors (copper & aluminum). It is significant that the principal thrust of the initial basic research (circa 1970) has shifted from a narrow concentrated effort on materials research to a broader research and development base. The focus of more recent R&D effort (circa 1980) is now diversified to include; improving the performance of current materials, developing manufacturing methods to reduce production cost, developing the methods and devices needed to make efficient and reliable interconnections.

Applications for patents have been filed as recently as June 1981 on methods for making high strength, light weight composite wire (intercalated graphite fiber).

In summary, it appears that the intercalated graphite material will have a positive impact on the future of power transmission for the U.S. Army in general and the Air Launch Cable Deployment approach in particular.

WIRELESS ELECTRIC POWER TRANSMISSION

Early in the Phase I program, UREA agreed to examine and report on the feasibility of wireless power transmission and the potential for using this technology to transmit power in the battle field.

The concept of utilizing either Microwaves or LASER's to

transmit power over reasonably short distances (1000 to 5000 ft.) may be feasible. The technology is partitioned into Generating & Sending Power (GSP) and Receiving & Converting Power (RSP). The more difficult design and development problems are associated with the RSP in general and the microwave receiving antennas in particular. The problems with the sending/receiving antennas are significant.

The use of high power LASERs, on the other hand, is generally considered to offer fewer development problems than microwaves. The authorities on this subject at Tufts University think that LASER power transmission could be developed in such a way that it would be difficult for the enemy to detect.

Thus, while both conceptual approaches are feasible the microwave system is considered to be a much longer, more expensive and higher risk development program than a LASER system of comparable power. However, it should be noted that neither the Microwave nor the LASER power transmission system could be demonstrated within the time constraints of the SBIR Phase II schedule.

Significant research activity to establish the feasibility of microwave power generation & transmission has been done under the program title: **SATELLITE POWER SYSTEM** (SPS). The research in this area is currently being performed at some large companies such as Raytheon under the sponsorship of NASA and DOE. The transmission distances involved with the SPS are significantly longer than that required for battlefield applications.

While research continues, the activity does not appear to be a high priority program at this time. UREA expects to maintain contact with Raytheon and continue to monitor progress in this important technology.

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2.0

PHASE I MAJOR TASKS
STATUS & SUMMARIES

2.1 INTRODUCTION

The major tasks have been organized into three groupings; Task I, Data Gathering; Task II, Analysis & Findings; Task III, Conclusions & Recommendations. All Phase I Tasks, as outlined in the proposal(1), have been completed to the extent necessary to satisfy the principal objective; i.e., establish the feasibility of the concept. There is a natural overlap in the tasks required to complete each phase of the program, e.g., a substantial amount of data gathered is applicable to the effort required to complete Phase II. Therefore, the percent completion status of each major task is assessed in terms of the requirements of a Phase I & II level of effort, see Table 2.1 below.

TABLE 2.1

STATUS OF COMPLETION . . . MAJOR PROGRAM TASKS

TASK NUMBER & TASK NAME	PHASE I % COMPLETE	PHASE II % COMPLETE
I, DATA GATHERING	100	50
II, ANALYSIS & FINDINGS	100	20
III, CONCLUSIONS & RECOMMENDATIONS	100	0

In general, the effort required for the Phase I, Tasks I, II & III are considered complete and **Level 0, Level 1 & Level 2** (Figure 3.1) conclusions and recommendations have been developed

and are presented below.

While additional Phase II work is required in certain cases, it is important to stress that each of the nine L 2 components is technically feasible. The level of detail that was examined and evaluated will not only support the conclusions pertaining to feasibility but also provide information for optimizing the concept and broadening the base of the design options and/or back-up concepts. For example, the L-2 component A_{11} KEVLAR REINFORCED CABLE (Figure 3.1) is both technically feasible and practical for the air launch as well as other more conventional applications. The level of detail examined for this component was down to the thread size & configuration of the Kevlar braiding that will be recommended to achieve a reasonable operating safety factor on the cable's tensile strength. The study strongly indicates that the normal quality of cable delivered to the DOD is below the SOA capability for cable manufacturing. This level of detail is reviewed on an individual component basis in the technical discussion pertaining to Task II, Analysis & Findings (Sect. 3.0).

2.2 TASK I SUMMARY
DATA GATHERING

INTRODUCTION

As noted in Table 2.1, the Phase I Task is 100% complete for this stage of the program and approximately 50% complete based on the anticipated Phase II requirements. The objective of this task was to obtain information pertaining to;

- o System operational information
- o Physical properties of cable & connector as they relate to both current & future MERADCOM requirements
- o Electrical power source data
- o Tactical equipment specifications & demonstrations

The data gathered are reviewed as part of the detailed technical discussion relating to the analysis and findings on each Level-2 system component (Figure 3.1). The exception to that

approach is the technical decision trade-off methodology (NSIA) which is incluced in Appendix B. The data source is noted in the attached bibliography.

TASK II
ANALYSIS & FINDINGS

INTRODUCTION

As noted in Table 2.1, this Phase I Task is 100% complete for this stage of the program and approximately 20% complete based on the anticipated Phase II requirements. The discussion of the analysis and findings that relate specifically to the feasibility study priorities, the conceptual design approaches and the general configuration of individual system components are reviewed in this section. Other elements of Task II are discussed in Section 3.0 of this report.

TASK III
CONCLUSIONS & RECOMMENDATIONS

INTRODUCTION

As noted in Table 2.1 the Phase I Task III is 100% complete at this stage of the program. There is sufficient information, technical data, preliminary configuration sketches and schematics now available to draw positive conclusions pertaining to the feasibility of both the principal and alternative concepts, as well as L-2 back-up component design concepts. The detailed written description, concept drawings and schematics have been prepared for submission and approval of Ft. Belvoir. The information and drawings that are available to support the conclusions noted in Section 4.0 and the Executive Summary are supported by the Analysis & Findings presented in Section 3.0 of this report. Thus, the level of completion reflects the status of the engineering drawings & schematics that are considered desirable to adequately describe the concept in its more refined state.

3.0

ANALYSIS & FINDINGS
RAPID DEPLOYMENT OF ELECTRIC POWER CABLES (RDEC)
&
ROBOTIC CABLE RETRIEVAL (RCR) SYSTEM CONCEPT

3.1 INTRODUCTION

PROGRAM MANAGEMENT STRATEGY

The RDEC/RCR System concept's functional components have been organized in a hierarchal group so that each can be studied separately but with an awareness of the constraints that apply in order to promote the final integration into an operating system (Figure 3.1). Each Level-2 (L-2) component has been assigned certain technical management variable attributes (TMVA's) early in the program; e.g., level of difficulty, design risk and priority. The TMVA's will vary over the course of a program as critical problems are solved and less obvious problems become apparent. Therefore, the feasibility study emphasis that is placed on the conceptual components will shift from time to time. Thus, the feasibility study priorities associated with each discrete component vary depending on the importance of their contribution to the performance of the system as a whole. For example, Figure 3.1 shows some nine components that are grouped according to related or interdependent L-2 functions; it is clear, from a system perspective, that the design of the reinforced cable (a high priority) is more important than the design of the manual deployment mode (a low priority).

BRIEF DESCRIPTION OF THE RDEC & RCR CONCEPT

While the RDEC/RCR System Concept deals with both deployment and retrieval of electric power cables, the major emphasis (high priority) is on the rapid and flexible deployment component. The RDEC concept is **flexible** in that it can accomodate deployment from conventional vehicles such as jeep, truck, aircraft, boat or manual methods. Each of the above methods, however, could require

several hours to connect the power source to a tactical position user. Since this amount of time-delay might be unacceptable under certain combat conditions, the **air launch concept** (Figure 3.2) was established to promote **very rapid** deployment, i.e., the deployment **time could be reduced to a matter of a few minutes.**

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The cable deployment team would merely connect the appropriate number of cables required to span the distance between power source and user. The power user end (PUE) of the cable would be attached to the TOW missile umbilical cord (Figure 3.2). The TOW missile would be launched and carry the light weight umbilical for the first few seconds of flight. At that point the missile will have reached full power and begin to assume the load (weight & mass inertia) of the electric cable. Since the TOW is a wire guided system with a reputation for extreme accuracy, it is anticipated that the cable can be delivered to a user located within a 1000 foot range with good accuracy (15 to 25 yds.). When the PUE & the Power Panel End (PPE) connections are made the deployment process is complete.

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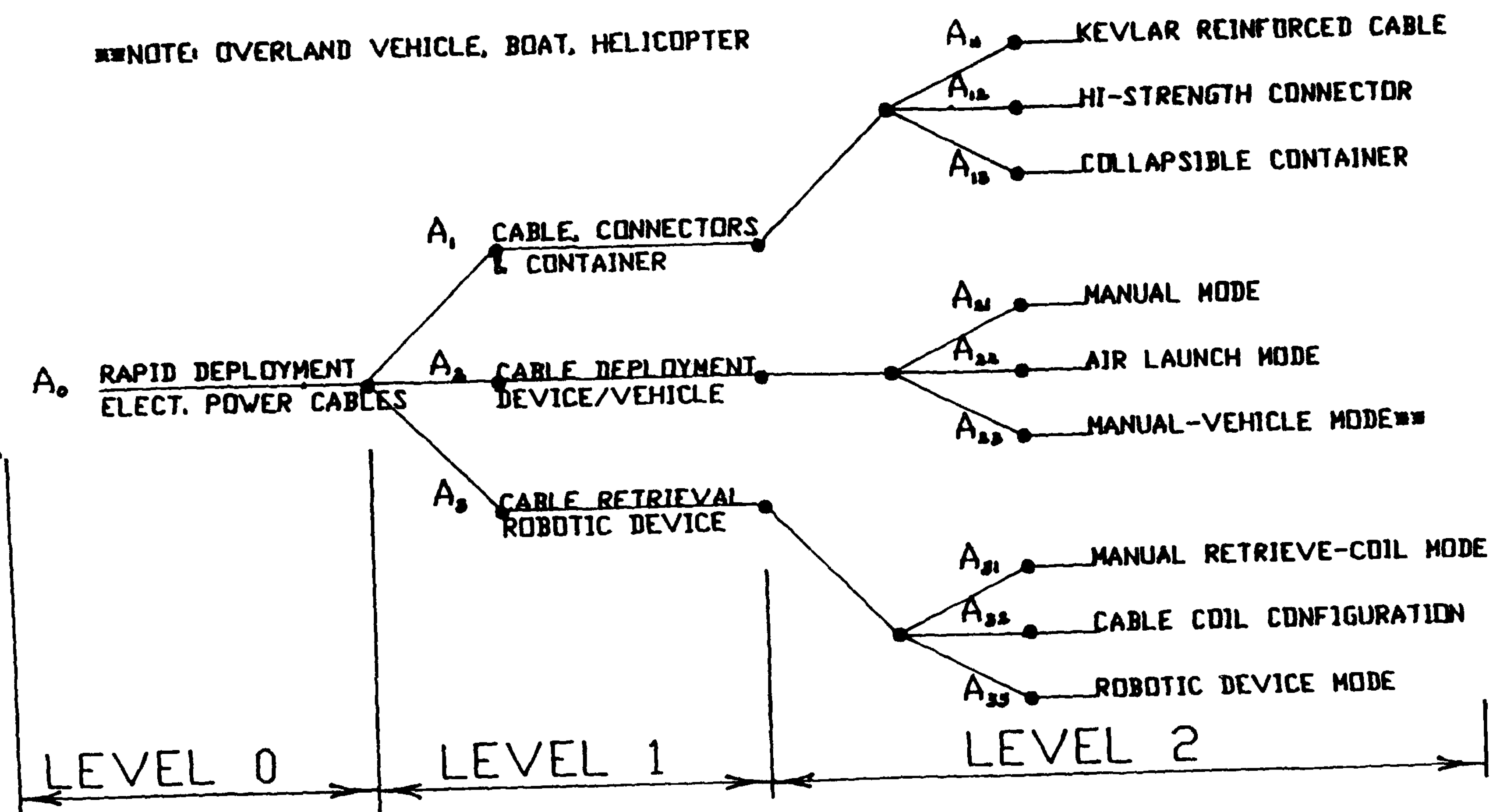
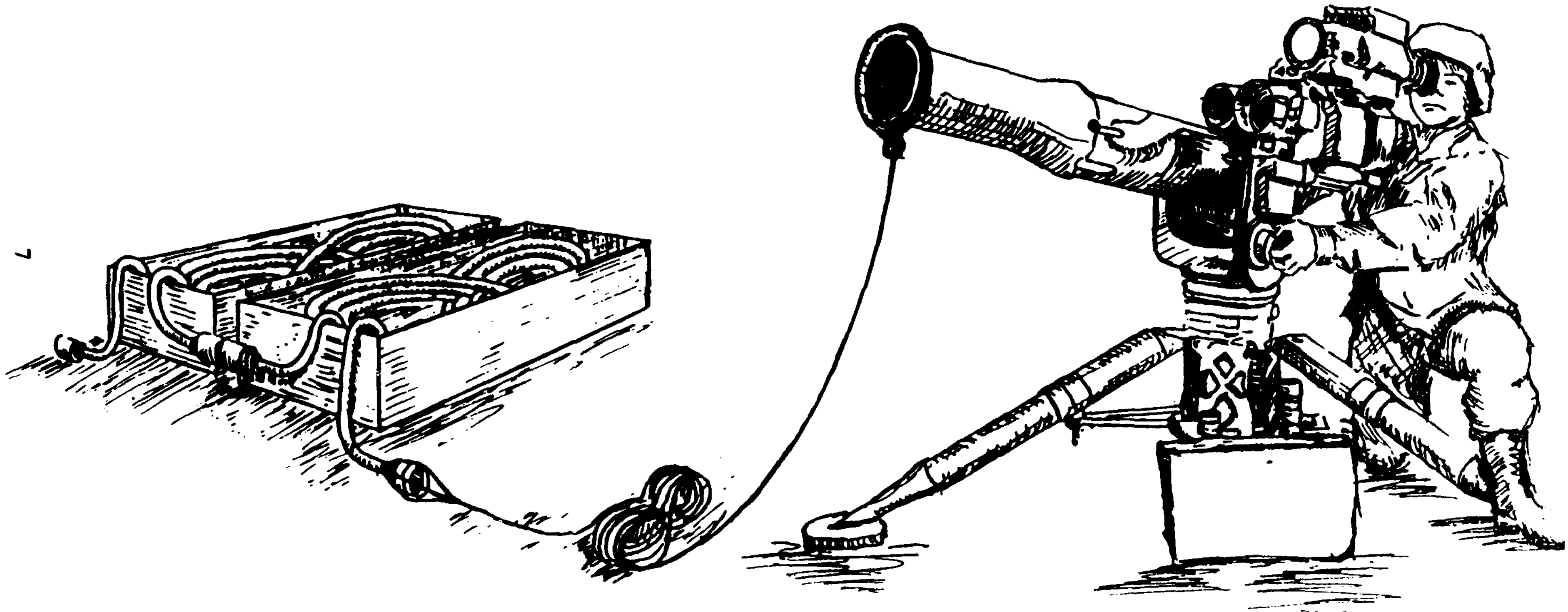


RDEC FUNCTIONAL COMPONENTS GROUPING HIERARCHY

FIGURE 3.1

UNIVERSITY RESEARCH ENGINEERS
AND ASSOCIATES, INC.
HERCULES, CA 94547
DESIGNER: TOM CALLAHAN
APPROVAL: Tom Callahan
S-DATE: / / C-DATE: / /
DWG. TITLE: FUNCTIONAL COMPONENTS



ARTIST SKETCH, TOW MISSILE AIR LAUNCH MODE

FIGURE 3.2

Biological, or Chemical (NBC) environment. The cleaning would take place before the cable could contaminate any of the retrieval or packaging mechanism. The device would also make the in-line disconnects, coil, package and cover the cable for storage. In addition, the capability to sense and distinguish the normal retrieval resistance from the loads developed by some obstruction would be incorporated into the mechanism and controls. Another important feature of the concept is the ability to develop some violent oscillations in the cable if it is needed to free it from the obstruction.

STUDY PRIORITIES

On a scale of 1 to 10, the highest priority (#1) was assigned, early in the program, to establishing the feasibility of constructing a prototype cable that could withstand the high tensile loads anticipated at the time of air launch. It seemed logical to give this component (A_{11}) the highest priority because an air launch mode would be meaningless without an adequate cable. A conventional commercial cable is inadequate for this type application. Thus, satisfactory data relating to the adequacy of this component was developed before pursuing the data requirements and conceptual details of other components. In order to accomplish this, a computer model was established to represent the dynamics of the concept and thus disclose the magnitude of the critical design parameters, e.g., tension load on the cable caused by the rapid acceleration of the missile, (Table 3.1).

The success of the air launch mode of the concept turned on developing an adequate computer model to yield meaningful cable design parameters as noted in Table 3.1. The computer simulation was developed by three Professors at Tufts University, Medford, MA and the most recent computation included data obtained from the TOW-SPO/MICOM. The computer model is reviewed in some detail in Appendix A.

In order to sharpen the R&D focus and reduce the amount of time required to investigate power cables, advice pertaining to sizes, applications, etc. was obtained from Ft. Belvoir.

Thus a #6AWG-4c power cable was selected as the prototype for the feasibility study but other cable sizes would be evaluated in Phase II.

TABLE 3.1

CRITICAL DESIGN PARAMETERS

- **TENSION & SHOCK LOADS APPLIED TO CABLE & CONNECTORS CAUSED BY AIR LAUNCH & RETRIEVAL**

- **AIR DEPLOYMENT APPROACH:
SINGLE INITIAL APPLICATION OF MOMENTUM (MORTAR)
VS. CONTINUOUS APPLICATION OF MOMENTUM (MISSILE)**

- **AERODYNAMIC DRAG OF THE CABLE ON THE HOST VEHICLE**

- **CABLE WEIGHT & MASS INERTIA IMPACT ON MISSILE PERFORMANCE (RANGE) & STABILITY (ACCURACY)**

- **DESIGN CONSIDERATIONS FOR THE TORSIONAL DEFLECTION OF THE CABLE (KINKS) AS DEPLOYMENT TAKES PLACE**

The preliminary evaluation of the basic air launch requirements was necessary to establish the more appropriate devices (in the DOD inventory) that might satisfy the parameters developed by the computer model (also a high priority activity). The evaluation covered both single impulse (mortar/howitzer) and continuous application of momentum (missile) devices. Thus the first and second priority levels dealt with rapid deployment, and the third tier priorities included the retrieval components. Other L-2 component priorities are shown in Table 3.2

TABLE 3.2

FUNCTIONAL COMPONENTS
DESIGN FEASIBILITY STUDY PRIORITY LEVELS

NUMBER	DESIGN DESCRIPTOR	PRIORITY NO
A_{11}	KEVLAR REINFORCED CABLE	#1
A_{12}	HI-STRENGTH CONNECTORS	#2
A_{13}	COLLAPSIBLE CONTAINER	#4
A_{21}	MANUAL LAUNCH MODE	#5
A_{22}	AIR LAUNCH MODE	#2
A_{23}	MANUAL-VEHICLE MODE	#4
A_{31}	MANUAL RETRIEVE-COIL MODE	#5
A_{32}	CABLE COIL CONFIGURATION	#3
A_{33}	ROBOTIC RETRIEVE-COIL DEVICE	#3

In terms of the total Phase I study effort, greater weight was placed on establishing the feasibility of the rapid deployment of the cables rather than on their retrieval (Table 3.2). The success of the study turned more on answering basic questions pertaining to developing two higher priority system segments, i.e., (1) A_1: a cable to withstand launch loads (Para. 3.2) and (2) A_2: a device to provide the launch mechanism and direction for rapid air deployment (Para. 3.3). When these questions were answered affirmatively, the study effort was directed toward evaluating the third segment of the system concept, i.e., A_3: improving the robotic cable retrieval concept (Para. 3.4).

3.2 LEVEL-2: RDEC COMPONENTS
A_1 CABLES, CONNECTORS & CONTAINER

3.2.1 A_{11} KEVLAR REINFORCED CABLE

A_{11} Kevlar Reinforced Cable: as previously noted, a successful cable design is fundamental to the RDEC concept and was assigned a #1 study priority. Preliminary discussions with DuPont indicated that, while they believed the application was feasible, engineering level estimates of the operating environment and design parameters must be supplied to the cable manufacturers before any definitive evaluation of feasibility could be established. Two candidate power cable companies (designers & manufacturers) were chosen from a preliminary list of over 25. Both companies had previous experience with power cables subjected to extreme loads (e.g.,tensile, torsion) in hostile environments (high temperature, corrosive atmosphere) that were, according to their estimates, much more severe than the projected loads of the air launch concept.

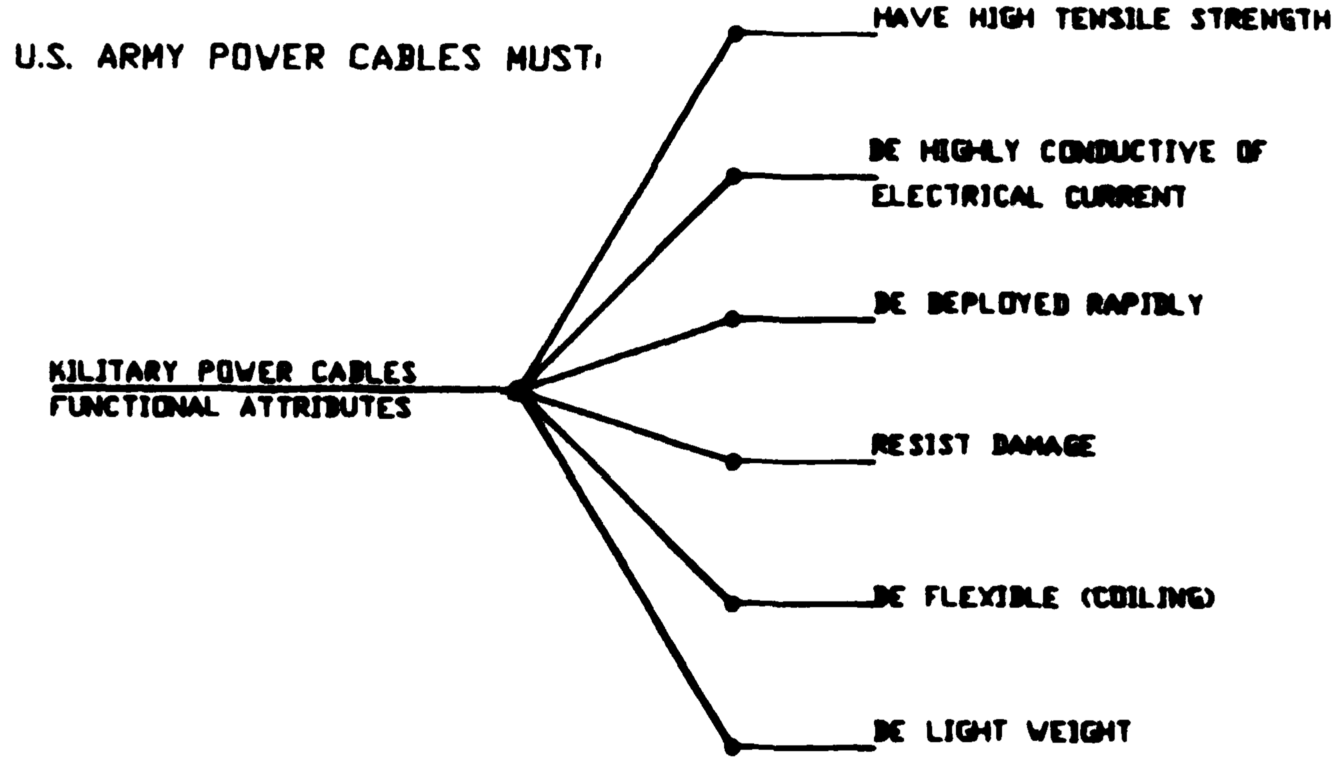
Based on preliminary estimates of the cable launch load parameters (2500 to 3000 lbs.), the cable designers judged that a cable, reinforced with a braided Kevlar (aramid fiber) prior to vulcanizing a neoprene outer jacket, could be developed. Their judgment was that the cable would not only survive in such an air launch environment but have a life cycle better than conventional cable. The computer model yielded design data that were in the same range (2000 lbs.) as the original estimates and the program moved foward rapidly at that point with only minor adjustments. Both manufacturers agreed to supply UREA with design & construction quotations based on the up-dated parameters for #6AWG-4c (copper wire) power cables (Figure 3.3) and the more important functional attributes (Figure 3.4).

It was apparent that the operating environment for the TOW Air Launch Concept, while moderately severe, was well within the capacity of a SOA cable. There was a consensus that, while Kevlar offered some weight to strength advantages over other materials (stainless steel, glass fiber, nylon, etc.), there was a cost

INTERIM CABLE SPECIFICATIONS
A.W.G. CONDUCTOR SIZE . . . #6
NUMBER OF CONDUCTORS . . . 4
INSULATION THICKNESS (IN.) 0.060
JACKET THICKNESS (IN.) . . 0.140
NOMINAL DIAMETER (IN.) . . 1.115
WEIGHT LBS./FT. . . . 0.862
BENDING DIAMETER (IN.) . . 9.0
AMPERE RATING 80.0

INTERIM CABLE SPECIFICATIONS

FIGURE 3.3



FUNCTIONAL ATTRIBUTES OF U.S. ARMY RAPID DEPLOYMENT POWER CABLES

FIGURE 3.4

penalty for that advantage. One manufacturer considered that other modern reinforcement materials might also be feasible but costs were prohibitive.

The air launch loads that were described to the cable manufacturers did not appear to offer any technical barriers to the cable development. Both manufacturers agreed that either a **flat** or a **round cross section** could be manufactured with relative ease. Thus, **the degree of the development risk associated with the use of Kevlar is considered to be relatively low.** This high confidence level on their part was reassuring. However, because this component is so important, UREA elected to examine the design and manufacturing process more closely in order to fully understand the SOA. In addition, questions relating to the potential for improving and/or optimizing the performance of the cable, the system concept, or both, beyond the Kevlar design required a more penetrating study. While a thorough design study should be part of the Phase II effort, the results of the Phase I preliminary investigation are summarized below.

A preliminary but penetrating study of both the cable design and manufacturing process leads UREA to believe that **the SOA of this technology, is below its immediate potential**. There is little question that in recent years the structural capability and other physical characteristics of power cables have been dramatically improved. The improvements, to date, result more from a change of some of the materials, e.g., Hypalon & Kevlar (both supplied by DuPont), rather than any fundamental change in either the cable design approach or the manufacturing process. **The indications are that the manufacturing process is a major limiting factor** in any **cable design innovation**. It appears that if a new cable design (including the use of new/innovative materials) cannot be made by the traditional equipment, e.g., extrusion equipment or braiding machinery, it is simply ignored. Many mature industries appear to follow this kind of policy and, as a result, innovations and advancements in the SOA are severely retarded. The two cable companies, with whom we are working, appear to be more progressive regarding their attitude toward design and manufacturing innovation.

CABLE DAMAGE FROM CRUSHING LOADS

A study of the Arthur D. Little (ADL) report suggests that their evaluation of the SOA of cable technology did not attempt to penetrate beyond the traditional cable configuration (flat vs round). On the surface, it appears that a flat cable has some coiling properties that enhance the air launch concept. After further evaluation however, UREA concluded that the potential for a cable developing a **stable on-edge configuration** after deployment is too great to risk recommending its use. The on-edge configuration has a greater damage potential from crushing loads than a round configuration.

While the ADL report suggested that flat cable might be better than the round configuration as it pertains to resisting damage from crushing loads, it did not examine the more basic and more meaningful **mode of cable failure when subjected to crushing type loads**. UREA developed a preliminary test protocol to aid in obtaining a better understanding of this failure mode. A summary of the test and conclusions are noted below.

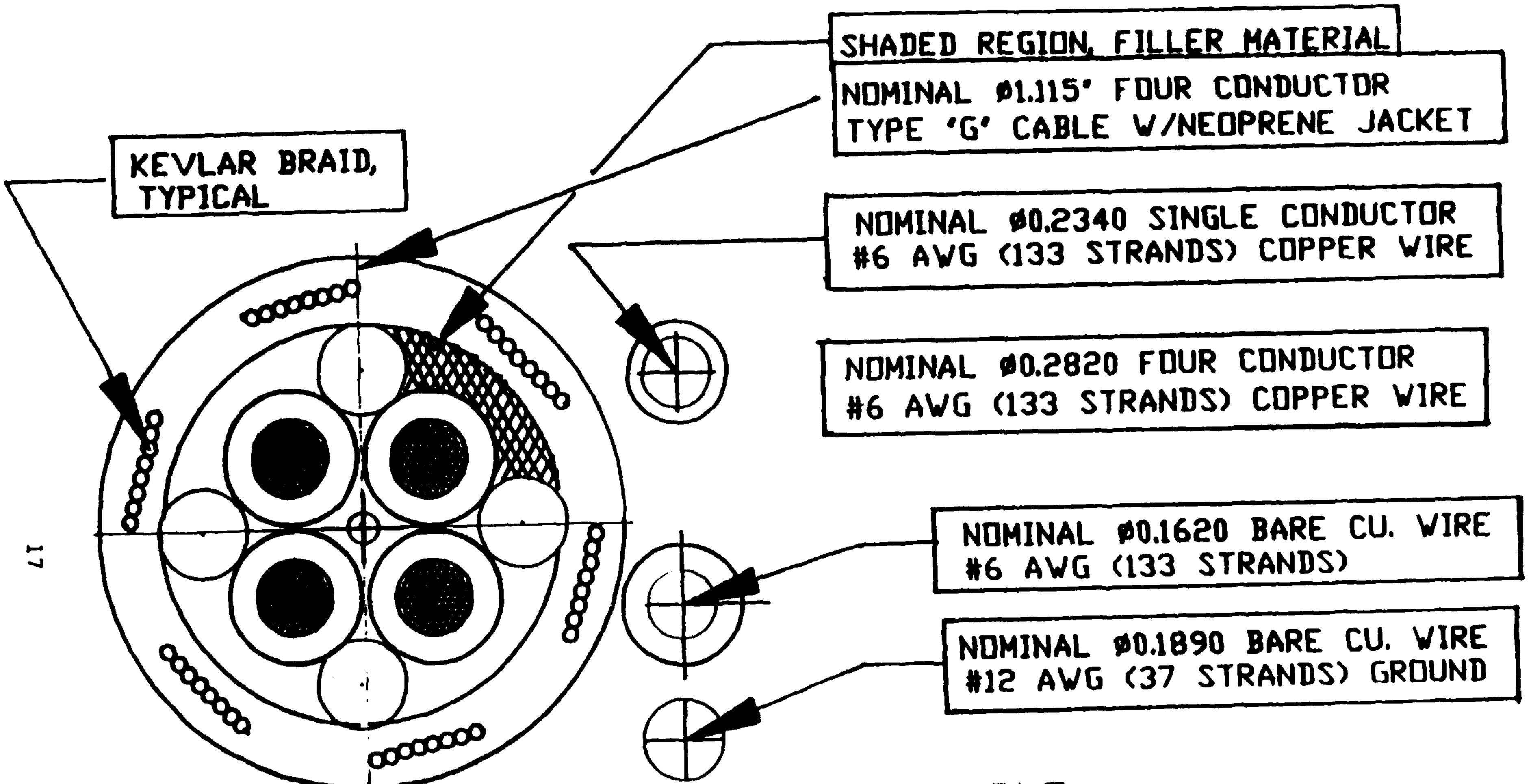
In recent years UREA has been involved in a design study directed toward establishing and optimizing the design approach to cable manufacturing (a manual/mechanical lay-up process) as used in avionics. Some of that experience bears on our estimates pertaining to the SOA of power cables and our observations relating to the cable performance evaluation in military field applications.

In an attempt to extablish the mode of failure, some **preliminary cable crushing tests** were conducted to observe the behavior of the cable as a large compressive load was applied by a steel plate. The first test (using a bench vise) demonstrated what might happen when the cable was crushed between two very rigid surfaces. There was little doubt that a flat cable has a marked advantage under these extreme circumstances. When the substrate was altered, i.e., made softer, the advantage appeared to diminish. In this second case, the cable was resting on the ground (firmly packed soil) with a steel plate placed on top. A vehicle was then slowly driven over the combination and the distortion of the round cable was carefully observed.

The individual conductors (round cable) quite noticeably moved relative to each other and the composite (including the outer jacket) formed an eliptical shaped cross section. The test was replicated several times with similar results. The test suggested that if the individual insulated conductors were more tightly twisted and bonded (cemented) together to maintain that shape; the failure mode could be altered. While the cable may eventually fail under these circumstances, the life cycle would be extended and the performance, under these circumstances, improved. Therefore, the cable was subsequently stripped and the individual insulated conductors were separated from the original bundle. A slow curing epoxy resin cement was applied to the conductors prior to tightly twisting the group of four and allowing the bundle to cure. The subsequent test clearly suggested that this tighter bonded bundle of twisted wires was a concept worthy of further study. The method of manufacturing the twisted bundle and the test protocol both require better control before definitive conclusions can be drawn. Based on our previous experience with cable lay-up procedures, the tighter twisting can result in a more flexible cable and a smaller composite outside diameter. Subsequent conversations with the cable manufacturer confirmed that cable geometry (lay) had a significant impact on several functional attributes that are of primary interest in this air launch concept (Figure 3.4).

An examination of the typical cable cross section (Figure 3.5) shows that, in most cases, filler materials are utilized for no better purpose than developing a smooth, cylindrical configuration prior to applying the outer jacket material. The approach develops the desired shape with less weight while utilizing inexpensive materials. It should be noted that the tightly twisted bundle uses more copper per linear inch of cable and is therefore slightly more expensive. However, because of the potential shrinkage in the outside diameter, thus utilizing less jacket material (neoprene), it is estimated that there would be a net decrease in the composite weight per unit length of cable.

In addition, the cable manufacturers use varying thicknesses of insulation on a single conductor depending on the application



#6 AWG 4-CONDUCTOR, TYPE 'G' POWER CABLE
WITH KEVLAR BRAID REINFORCEMENT

COMPONENT A,,
FIGURE 3.5

(Figure 3.5). This can have a significant impact on other cable design parameters, e.g., stiffness/flexibility, outside diameter and weight.

Based on both the parametric study, past experience and the testing to understand the mode of failure, it is concluded that significant improvements in performance can be achieved with SOA cable materials. UREA has developed what appears to be a unique concept (patentable) for an integrated cable/connector design that will be explored in depth in Phase II. However, both the cable design and the manufacturing process might require alterations. Further cable development and performance testing is recommended in the Phase II program with an objective to improve the functional attributes of military power cable as noted in Figure 3.4.

INNOVATIVE CABLE DESIGN CONCEPT

As noted in the discussion of the preliminary crushing test, the conductors tend to move relative to each other as the elastomer insulation compound distorts under the extreme compressive force. Central to the concept is the thesis that by limiting the motion between the cable's core conductors, eliminating useless fillers, and reducing the cable cross section will result in a cable with better performance attributes for all-around use but in particular for the rapid (air launch) deployment application.

The design concept focuses on cable configuration as the primary technical influence on the design while recognizing that the material and manufacturing process also have a major impact. For example, one of the most important material properties that will influence the final design approach is whether it is a thermosetting or a thermoplastic process.

CORE MATERIAL is considered to be a stranded copper wire (Figure 3.5) with an electrical insulation material of minimum permissable wall thickness. The individual conductors and ground would be tightly wound (coiled) over a center strand of Kevlar cord (diameter to be determined) in such a way that when the torsional forces required for coiling are removed the tight spiral

configuration will remain. Before the torsional forces are removed, the core bundle would be tightly over-braided with a fine pitch, fine strand, Kevlar thread. The tension force on the Kevlar thread is considered essential to the concept.

TABLE 3.4

INTERIM PERFORMANCE REQUIREMENTS:
ELECTRIC POWER CABLE, RAPID DEPLOYMENT TYPE

ITEM NO.	PRIORITY NO.	PERFORMANCE REQUIREMENT & DISCRIPTION
1.0	1	PROVIDE LOW ELECTRICAL RESISTANCE
2.0	1	PROVIDE HIGH TENSILE STRENGTH
3.0	1	REDUCE CABLE WEIGHT
4.0	2	PROVIDE LOW TORSIONAL MODULUS (FLEXIBILITY)
5.0	2	PROVIDE LOW BENDING MODULUS (FLEXIBILITY)
6.0	2	RESIST CRUSHING LOAD DAMAGE
7.0	2	DEPLOY EASILY & RAPIDLY
8.0	3	PRODUCE CABLE AT LOWEST COST
9.0	1	PROVIDE A WATERTIGHT OUTER JACKET

The **OUTER JACKET** could be a more traditional reinforced (Kevlar braid) neoprene or similar abrasion resistant material. This type outer jacket is judged to be a suitable armor against the external crushing forces from ground vehicles. It should be pointed out that using Kevlar sheet material is common practice for Bullet-Proof outer wear applications.

The **KEVLAR CENTER CORD**, a primary tensile member is directly connected to the molded connector that is integral to the cable. More details are discussed in the paragraph Titled: A[12] HI-STRENGTH CABLE CONNECTOR.

CABLE DESIGN CRITERIA

The cable design will be measured in part against the following criteria as a minimum. There are other MIL Specs. & STD. that also apply and will be established.

DOCUMENT NO.	TITLE AND/OR DESCRIPTION
ANSI/UL 4-1980	SAFETY STANDARD FOR ARMORED CABLE
ANSI C8.36	. . THERMOPLASTIC INSULATED WIRES & CABLES
ANSI/IPCEA S-28-357	
ANSI/NEMA WC1-1963	
ANSI/ASTM B105-80	SPECIFICATIONS FOR . . . ELECTRICAL CONDUCTORS
ANSI/ASTM B1-70	
ANSI/UL 1063-1975	STDS. FOR MACHINE TOOL WIRES & CABLES
ANSI/UL 719-1979	STDS. FOR NONMETALIC-SHEATHED CABLES
ANSI/ASTM D1351-70	SPECS. FOR POLYETHELENE INSULATED WIRE . .
ANSI/UL 44-1977	SPECS. FOR RUBBER INSULATED WIRE & CABLE
ANSI/ASTM B48-68	SPECS. FOR STD. NOMINAL DIA. & CROSS SECTION AREA OF AWG SIZES . . .
ANSI/ASTM D2633	TESTING THERMOPLASTIC INSULATED CABLE
ANSI/UL 83-1979	SAFETY STDS. FOR THERMOPLASTIC INSUL. WIRE
ANSI/UL 493	SAFETY STDS. FOR UNDERGROUND THERMOPLASTIC INSULATED WIRE & CABLE

3.2.2 A_{12} HI-STRENGTH CABLE CONNECTOR

One of the two chosen cable companies believes that their proprietary cable connector will satisfy the general operating requirements and design criteria that UREA outlined to them. In addition, a preliminary sketch of a unique cable connector concept was suggested in the original proposal(1) titled: Breech Lock Type Cable Connector. This design was discussed on a preliminary basis and the details were purposely deleted until the nondisclosure requirements of the U.S Patent Office could be satisfied. It appears that, with minor modifications, either the exixting or the unique connector approach will satisfy the needs of the program and it is more likely that some synthesis of these designs will emerge as the

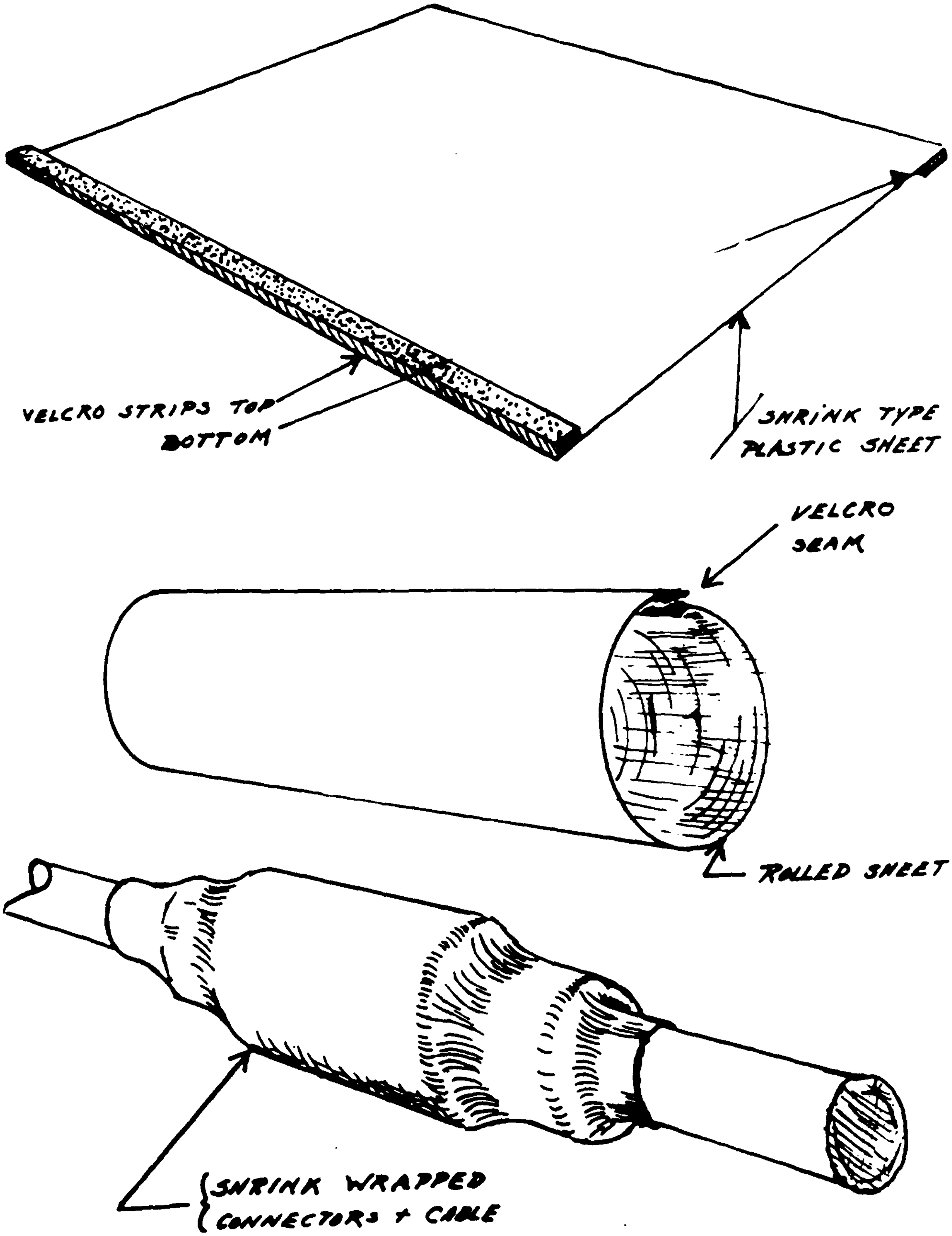
device that will meet the program needs and other longer range manufacturing considerations and cost. In any case, there is good reason to be optimistic that this interaction between two designers will result in an innovative connector that will satisfy Ft. Belvoir's requirements. The preliminary breech lock connector sketch (Fig. 3.6) has been modified and upgraded.

AUXILIARY CABLE CONNECTOR PROTECTION

The possibility of providing an **Auxiliary Environmental Protection Sleeve** (Figure 3.7) over the connector joint to supplement or enhance the environmental seal (e.g., moisture, dirt, oil or corrosive gases) of the connector was suggested (page 11 of the proposal). There are a number of innovative opportunities to accomplish this task. The more significant problem is to find a way to satisfy some important operating requirements, e.g.;

(1) easy attachment
(2) lighter weight
(3) abrasion resistant.
(4) lower cost

An approach that satisfies the requirements is the use of Velcro strip (hook & loop type fastener) bonded to a sheet of biaxial oriented vinyl acetate (a heat shrinkable material). While the system could be assembled in the field, it would be easier, from a logistic perspective, to supply it as part of the original cable/container component (Figure 3.4). To apply the auxiliary seal, the operator would join the male to female cable connectors, wrap the sheet around the joint, apply slight pressure (by hand) to the seam formed by the sheet and the edges of the Velcro fastener material (which is now oriented parallel to the longitudinal axis of the cable). The heat source required for the shrinking operation could be obtained from anything on site such as the exhaust from a truck or a diesel engine generator. After the heat is applied, the material will shrink down tightly around the connectors. When the material cools, a few of seconds after the heat is removed, it will permanently retain that final shape.



AUXILIARY CONNECTOR SEAL

FIGURE 3.7

To disassemble the seal, the Velcro is simply peeled back and the connectors are exposed. The auxiliary seal material can be salvaged and reused or discarded. There are a number of advantages to this approach but the environmental seal is the most important.

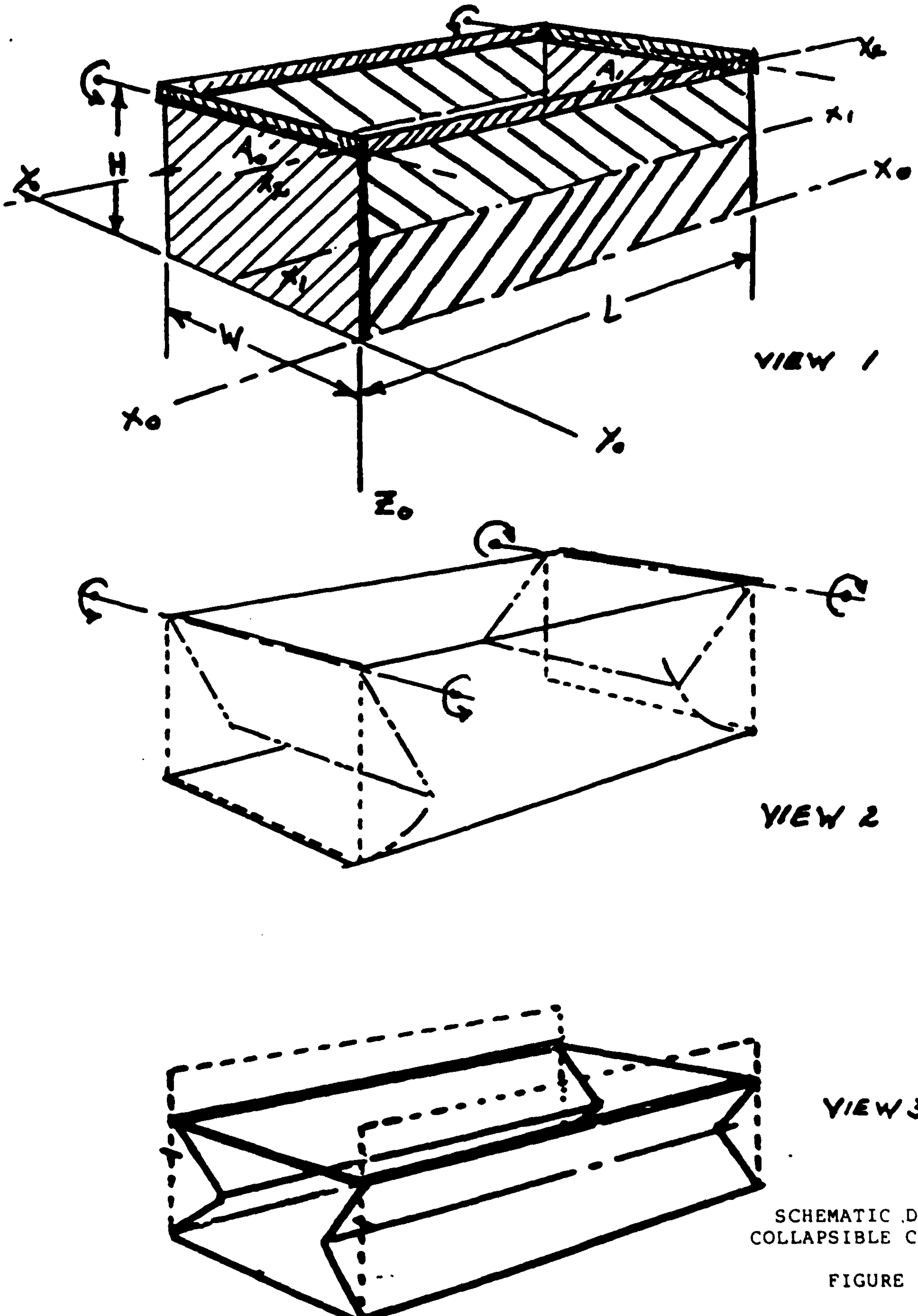
3.2.3 A_{13} COLLAPSIBLE CONTAINER

In general, the power cable must be packaged and transported from CONUS to the operating theater and then to the deployment site. One packaging method is to wind the cable on the mandrel of the traditional reel. This method adds a significant inertia to the cable when it is unwound rapidly. In the proposed deployment concept the mass inertia must be kept to a minimum. This can be accomplished by eliminating the reel and developing an alternative coiling and packaging method.

One such coiling method, the Flake-Eight (see A_{32} Cable Coil Configuration) requires a rectangular type container. The container could be either a disposable or a permanent type unit. If the cable is to be retrieved, repackaged, and stored before redeployment, then a permanent type container should be considered. That means that the design of the container itself must be given careful consideration so that it can serve as a rugged container for cable storage and transportation purposes. In addition, after the cable is deployed, the container itself must be easily stored. Therefore, a container that is both rugged and collapsible might satisfy some logistics problems. A schematic of the primary concept is shown in Figure 3.8.

COLLAPSIBLE CONTAINER FUNCTIONAL ATTRIBUTES AND REQUIREMENTS

In general, if a collapsible container is to become a viable part of the rapid deployment concept, it must perform a prescribed set of functions and be manufactured at a reasonable price. Since the container will be constrained to perform these functions in a predetermined way, it makes sense to prioritize both the functions and design/performance (D/P) constraints that might be applied to the Phase II prototype container. If a trade-off between functions or performance becomes necessary, the priorities will be



SCHEMATIC DIAGRAM
COLLAPSIBLE CONTAINER

FIGURE 3.8

helpful in the NSIA methodology (re: Progress Report #4).

The **Principal Functions** (i.e., what the component must do) will be prioritized first followed by the **Performance Requirements** (i.e., how the component will perform the function). The **Design Criteria** that will be utilized to measure the effectiveness of the design approach will be examined but not prioritized.

ITEM NOS.	FUNCTIONAL ATTRIBUTES/REQUIREMENTS & DESCRIPTIONS:
1.0	**Provide Cable Protection** . . Provide protection to cable against damage or environmental deterioration during **Storage & Transportation**;
2.0	**Enhance Cable Deployment** . . Provide minimum resistance to the rapid removal of the cable from the container
3.0	**Facilitate Rapid Cable Assembly** . . Provide an easily removable cover and ready access to the male & female cable connectors and sufficient cable slack to allow for a rapid connection to an adjacent cable (in container)
4.0	**Facilitate Material Handling** . . Provide for easy handling by either manual or mechanical methods (e.g., light weight & rigid - high compressive strength to support a stackable configuration, etc.)
5.0	**Facilitate Storage of Empty Container** . . Provide a method of reducing the size (outside dimensions) of the empty container so that it can be easily stored

6.0 **Promote Low Manufacturing Cost** . . The detailed container design must provide for the lowest cost manufacturing process and assembly methods

Design/Performance Constraints

It is important to note that the design constraints will have a significant impact on the performance and cost of both the individual components as well as the total system. Therefore, the design approach and/or constraints should receive careful consideration in the conceptual stages; i.e., before the detailed design is initiated.

Many of the D/P constraints will have either a positive or negative impact, in varying degrees, on the container's Principal Functions. For example, it is very difficult to maximize both the rigidity and strength of the container without adversely affecting the manufacturing cost. Therefore, it is important to examine constraints within the framework of each function and also within context of the complete device. For example, a very rigid container has a significant positive impact on the performance characteristics of several higher priority functions, e.g., items #1, Provide Cable Protection & #4, Facilitate Material Handling (#5, Facilitate Storage of Empty Container, to a lesser extent) while having a significant negative impact on the lower priority function #6, Promote Low Manufacturing Cost.

ITEM NOS.	DESIGN/PERFORMANCE CONSTRAINTS:
1.0	**Rigid Panel Structure**
2.0	**Light Weight Materials & Construction Methods**
3.0	**Environmental Protection/Seal**; auxiliary material permitted, e.g. cable wrapping
4.0	**Stable Assembly** (structure); in either the Fully Open or the Collapsed Configuration

5.0		**Safe & Convenient Handling Configuration**; either as individual containers or in groups, by mechanical material handling equipment and methods
	5.1	**Manual Handling Considerations**, e.g. grips or handles
	5.2	**Stackable Configuration**; (Top & Bottom), e.g., the Bottom of one unit will partially pilot into the Top of another to develop a stable stack of at least ten full containers
6.0		Outside dimensions of a group (a rectangular array) of containers should fit within the dimensional limits of a Standard ISO* Shipping Pallet
7.0		**Conforms to appropriate ANSI** & Military Standards**

* International Standards Organization or ISO

** American National Standards Institute

DESIGN CRITERIA

Considerable thought is being given to establishing comprehensive criteria that can be used to measure how well the detailed design (& its physical implementation) support the principal functions and the performance requirements. The Military Standards and the ANSI Standards governing the test procedures and performance criteria must be reviewed and the more meaningful elements summarized. Both the summary and recommendations pertaining to adoption will be submitted early in Phase II.

A body of material has been examined in Phase I. Comprehensive recommendations will be made when more of the information requested (Mil Stds) or purchased (ANSI Stds) have been reviewed. Portions of the following standards are considered applicable:

(1) Compression Test for Shipping Containers ANSI/ASTM

D642-76

(2) Drop Test . . . ANSI/ASTM D775-80

(3) Shock Test . . Recommended Practice, ANSI/ASTM D2956-71

(4) Water Resistance of Shipping Containers . . . Water Spray Test Method . . . ANSI/ASTM D951-51

(5) Definition of Terms Relating to Shipping Containers, ANSI/ASTM D996-76

PRIMARY COLLAPSIBLE CONTAINER CONCEPT DESCRIPTION: DESIGN SCHEMATIC

Considering both the functions and constraints noted above, a concept for a collapsible container was developed (Figure 3.5). The Rectangular Collapsible Container is made up of nine major structural elements that include eight main Panels, i.e., the Top Cover & Bottom Panel (not shown), two End Panels shown in the color red and four Side Panels shown in green. The ninth element, the Upper Frame, is shown in black. The two End Panels (red) pivot about pins whose major axis lies along the Y-Y axis. When the container is fully opened and locked, the End Panels are in a vertical attitude and locked in place by a spring loaded detent located in the Bottom Panel.

In order to collapse the container, a horizontal force is applied at the lower extremity of the End Panels. The panels are pushed in toward the center of the container and pivot about Y-Y pins that are located in the Upper Frame (black).

Each of the two pairs of Side Panels pivot about pins whose major axes are parallel to the X-X axis (X_0, X_1 & X_2). The Lower Side Panel rotates in a counter clockwise direction about the X_0 while the Upper Side Panel rotates in a clockwise direction about the X_2. Both Panels rotate simultaneously about X_1 as that axis translates inward and downward. Since the X_2 axis is integral with the Upper Frame (black), it moves in a vertical direction downward until it touches the Bottom Panel.

The dimensions of the container's panels must be carefully selected in order to minimize the collapsed silhouette.

3.3 LEVEL-2: RDEC COMPONENT

A_2 CABLE LAUNCHING DEVICE/VEHICLE

Because of the low study priority (Table 3.1) components A_{21} & A_{23}, the Manual and Manual-Vehicle Modes, will not be discussed in any detail. Generally, these manual modes are used as part of the current deployment procedures. However, the conceptual packaging approach should make these procedures much easier.

3.3.1 A_{22} AIR LAUNCH MODE

GENERAL STUDY BACKGROUND:

As a priority #2 component, the Air Launch Mode has received and will continue to receive a significant portion of the technical effort. There are three viable air launch device concepts that are currently being evaluated. However, in deference to both cost and logistics burden, the primary concept should employ a device that is already in the DOD inventory, if possible. A number of such devices in the Army inventory were investigated, e.g., TOW, STINGER, DRAGON, 155mm HOWITZER, and the MK 19-3, 40mm GRENADE LAUNCHER to name a few. The initial possibilities were narrowed early in the Phase I program to the **Tube-Launched, Optically Tracked, Wire Guided (Command Link) Missile System** that is more generally known by its abbreviated title: **TOW Missile System** (Figure 3.2).

The early air launch analysis (Appendix A) performed at Tufts University indicated that a controlled thrust device such as a missile would be more appropriate for the concept than a high initial impulse type device such as the grenade launcher, howitzer or mortar.

TOW ATTRIBUTES

An evaluation of the attributes of TOW indicated that the system offers substantial deployment advantages over other candidate systems. For example, it is widely used, and thus readily available, because it is an effective and reliable weapon system. The system has been up-graded several times which indicates that its useful life cycle has been extended many years

into the future. One of the more recent up-grades was the addition of a forward-looking infrared sight to provide the capability to see targets through darkness, haze and smoke, a distinct advantage if it were used to deploy power cables. The missile is deployed as a part of many different weapons systems, e.g., a single TOW mounted on a tripod for use by the infantry (Figure 3.2), 2 to 4 TOW's mounted on the side of a helicopter (re: AH-IS COBRA), 12 TOW's mounted on the Improved TOW Vehicle, a single TOW mounted on a CUCV or HMMWV. TOW is also used on the Bradley Fighting Vehicle.

The general system specifications are:

WEIGHT (launcher)	205 lbs.
WEIGHT (missile)	40 lbs.
RANGE	3,750 Meters.

TECHNICAL EVALUATION: TOW SYSTEM AS APPLIED TO THE CABLE AIR LAUNCH MODE

Based on the results of the computer model and other research, UREA personnel were optimistic that the TOW system offered all the preliminiary deployment attributes and technical characteristics required of the air launch system. After accumulating sufficient technical information, the TOW System Program Office (SPO) was contacted and the proposed concept was reviewed in detail.

In general terms, the SPO was optimistic that the TOW could be used as a cable deployment device. The opinion was qualified to the extent that the SPO strongly suggested that RDEC designers should work closely with TOW engineers to assure that the required attachment of the cable to the missile was designed such that any disturbance to the in-flight characteristics is minimized. This approach to a cooperative design effort would be enthusiastically embraced by UREA.

The SPO suggested that an annular, light weight, ring could be attached to the end of a high strength light weight cord (a Kevlar umbilical cord might be suitable) which, in turn, would be attached to the electric power cable. The annular ring would then be mounted to the exit end of the missile launch tube. When the missile was fired, it would pass through the center of the

annulus. The ring would be designed to lock-on the missile at the center of gravity and thus minimize any disturbance to the balance of the missile. It is important to the exterior ballistics consideration that the missile is not burdened immediately with the weight of the power cable for as long into the initial stages of the flight as possible. The velocity of the missile as it exits the launch tube is 220 ft./sec. which is maintained for approximately 1.5 seconds before the main propulsion rocket motor "kicks in". The velocity rapidly increases to approximately 1000 ft.per second. and the missile is basically at full power. At this point in the trajectory it is reasonable to have the missile begin to pick up the load of the power cable.

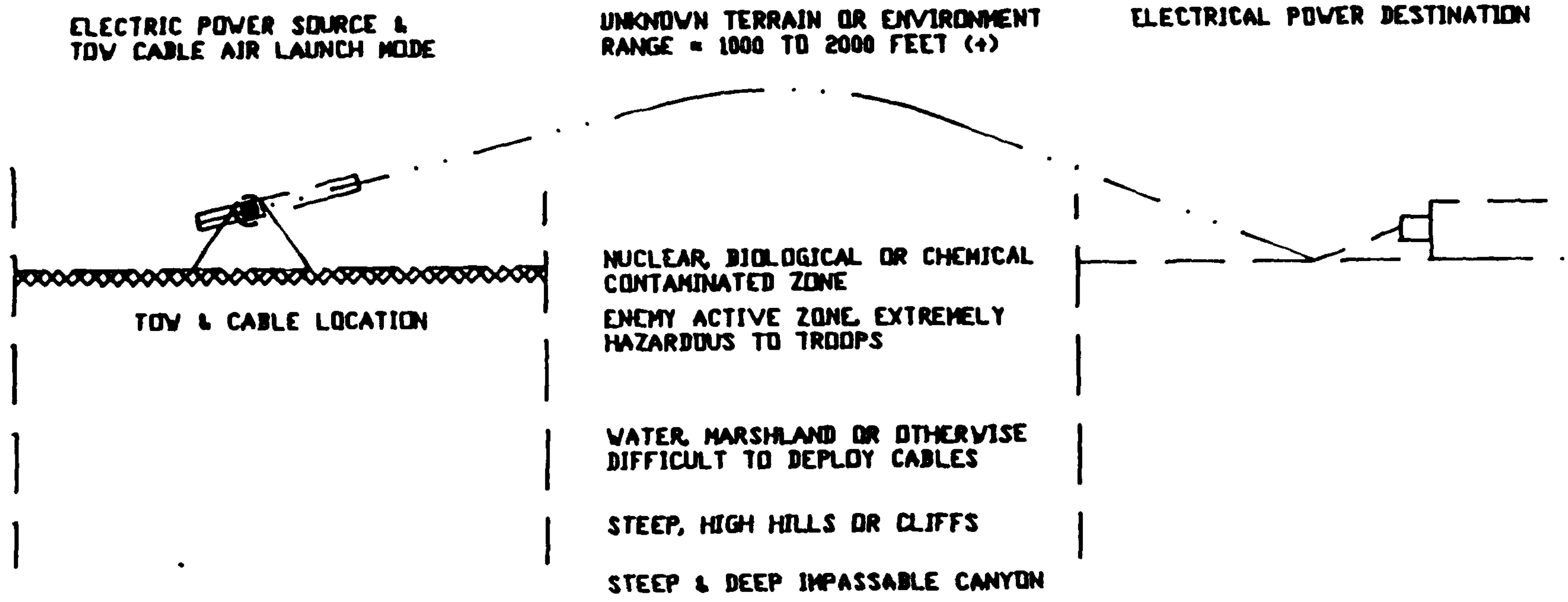
There are two principal operating scenarios that appear to be feasible:

(1) A **FLY-BY APPROACH** where the missile would fly by the tactical position and jettison the power cable at an appropriate point in the trajectory. The free fall would deliver the cable near enough to the target so that it could be easily retrieved by ground personnel.

(2) A **TARGET IMPACT APPROACH** where the missile would be directed at a predetermined target. The missile would impact at that target point and part of the Umbilical Cord would be destroyed leaving the power cable intact

The SPO discussed the concept with their missile flight simulation staff at Hughes Aircraft (Tucson, AZ). There was general agreement that while their computer simulation might show the concept to be feasible, a flight test would be required before anyone could be absolutely certain that "the bird will fly".

UREA was advised that testing at the MICOM missile test site can be arranged through Ft. Belvoir if the program moves forward to Phase II.



AIR LAUNCH MODE:
OBSTACLE NEUTRALIZATION

FIGURE 3.9

3.4 LEVEL-2: RCR COMPONENTS

A_3 CABLE RETRIEVAL - ROBOTIC DEVICE

3.4.1 INTRODUCTION

In terms of the total Phase I study effort, greater weight was placed on establishing the feasibility of the rapid deployment of the cables rather than on their retrieval. The initial success of the study turned more on answering some basic questions pertaining to developing two higher priority system segments, i.e., (1) A_1: a cable to withstand launch loads and (2) A_2: a device to provide the launch mechanism and direction for rapid air deployment. When those feasibility questions were answered affirmatively, the study effort was directed toward evaluating and improving the third segment of the system, i.e., A_3: the robotic retrieval device concept (Figure 3.1).

The conclusions and recommendations pertaining to the A_3 component are discussed in section 3.4.2.

The diversity of circumstances that can exist during retrieval as well as their relationship to or impact on the A_3 functions suggest that they should be carefully considered, e.g.:

(1) the human factors,

(2) the terrain,

(3) the environment

(4) the combat conditions

The human interaction with each component is described as an integral part of that component design concept. However, the methods that might be employed to retrieve and coil the cable manually are considered as a separate system component; A_{31}.

Two major cable design requirements are that it must be both strong enough to withstand the loads imposed by the primary deployment mode (air launch) and, at the same time, offer minimum resistance to the deployment mechanism. In other words, the cable must be stored in a container/coil configuration that will offer maximum protection from damage during transportation and minimum resistance during deployment or unpackaging. The design considerations for establishing a coil configuration (A_{32}) that offer a realistic compromise between the two requirement are

discussed below.

A third cable design requirement is that it must be strong enough to survive the retrieval loads. While the possibility of overloading a cable to the point of failure during manual retrieval is remote, it is possible (depending on the cable reinforcement design). The probability of developing an overload increases with the introduction of mechanical devices, e.g. winch, to assist the human operator. Therefore, it is important to introduce and discuss some of the more obvious circumstances (e.g., environment, terrain, combat conditions) and their influence on the retrieval concept. A comprehensive test program can be developed and implemented during Phase II to validate the hypothetical circumstances.

While a robotic type mechanism, autonomous or semi-autonomous, to retrieve and coil the cable is a design challenge, there is a very high confidence level that a Phase II demonstration of this component would be successful. The Ad Hoc Subgroup on Artificial Intelligence & Robotics of the Army Science Board suggested(1) that the initial (short term) design, development and implementation of Army robots should incorporate teleoperated controls. In addition, a program of **"PrePlanned Product Improvements"** (P^3I) should be included as part of the (long term) product life cycle plans. Thus, the integration of Artificial Intelligence, Expert System (AI/ES) technology will proceed smoothly at a future date. This approach is particularly appropriate in the RDEC concept since there is no relevant retrieval experience to provide a basis for the "Expert Knowledge". Thus, it is recommended that the Army Science Board's teleoperated robot design approach be adopted in Phase II.

While the concept for a retrieval robot will be both innovative and unique; the mechanisms, control hardware, software and instrumentation (sensors) can be designed, developed and demonstrated within the limits of current technology. Therefore, UREA considers that a semi-autonomous (teleoperated) robotic device to retrieve & coil power cable is more practical and represents the least development risk and a cost effective approach to MERADCOM. Thus, a design objective is to configure the

device to perform in as many field situations as appear to be operationally reasonable in order to assure cost effectiveness. For example, it is technically feasible to design the robotic device to function underwater but it is questionable whether this capability is either reasonable or cost effective.

A_{31} MANUAL RETRIEVE-COIL MODE

The discussion of this component will be brief since the actual method will depend on the final configuration of the coiled cable. The Flake-Eight Coil (Figure 3.10) appears to be optimum for this application. It has been used for many years by seamen for storing small (1/2" dia.) to large (2" dia.) line. One of the important aspects of this configuration, as it relates to retarding the formation of kinks, is the length of the lay, or elongated side of the coil, (Figure 3.10). The longer the lay permitted, the easier it is to apply a slight twist to the line as it is coiled.

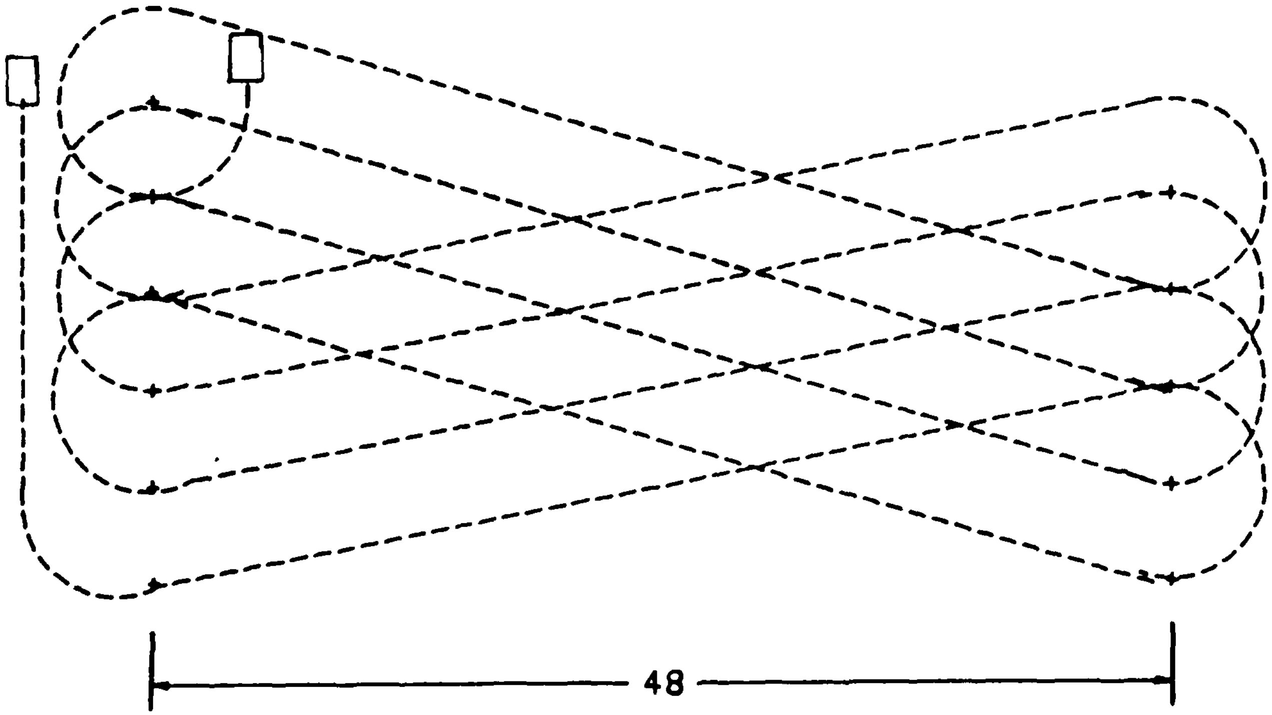
While the length of the lay has not been established at this stage of the development, the general characterictics of the coil are understood and the manual approach can be described. With some practice the cable can be coiled manually but the easiest way to develop a uniform coil is to make and use a temporary fixture. A series of stakes are driven into the ground at uniform intervals at each end of a rectangle. The size of the rectangle would be slightly smaller than the storage container. The operator would merely walk the cable back and forth using the stakes as a fixture to form the loop end of the Flake-Eight.

A_{32} CABLE COIL CONFIGURATION (Figure 3.10)

The cable coil configuration, as previously noted, is an important consideration in the rapid deployment concept. The tendency for a line or cable to develop kinks is the most significant problem that results from uncoiling a flat coil. It is analagous to applying a straight tensile force to a linear coiled spring. A linear motion (deflection) of the applied force takes place but the internal strain energy is torsion/shear.

INTERIM CABLE SPECIFICATIONS

A.W.G CONDUCTOR SIZE . . . #6
NUMBER OF CONDUCTORS . . . 4
INSULATION THICKNESS (IN) 0.060
JACKET THICKNESS (IN) . . 0.140
NOMINAL DIAMETER (IN) . . 1.115
WEIGHT LBS./FT. 0.862
BENDING DIAMETER (IN) . . 9.6
AMPERE RATING 80.0



SCHEMATIC DIAGRAM
CABLE IN-PACKAGE CONFIGURATION
THE FIGURE EIGHT FLAKE

FIGURE 3.10

UNIVERSITY RESEARCH ENGINEERS
AND ASSOCIATES, INC.
HERCULES, CA 94547
DESIGNER: TOM CALLAHAN
APPROVAL:
S-DATE: / / C-DATE: / /
DWG TITLE:
PROJ. SYMBOL

If the coil is extended far enough kinks will form. Thus, a uniform small diameter flat coil that is uncoiled by moving the ends in a linear direction promotes a large number of kinks. The stored garden hose is a good example of this condition.

The reel is often used to eliminate the kinking problem in some of the less demanding applications. Unfortunately, the reel adds unnecessary inertia to the air launch mode and an alte_ .tive method for eliminating this problem must be developed.

The design considerations that lead to the Flake-Eight configurations are:

- the need to develop a compact package for logistic purposes
- the need to eliminate the reel because of the inertia loads that would be applied to the missile
- the need to implement a simple but effective way to compensate for torsional stress developed in the coil as it is deployed.

The basic thesis supporting the elongated Flake-Eight coil is the fact that the clockwise angular deflection of the cable that takes place during linear deployment can be negated by pre-twisting the cable in a counterclockwise direction as it is being coiled.

The torsional stiffness of the cable is a function of its cross section (polar moment of inertia), modulus of elasticity, and length. For a given cable, the only parameter over which some control can be exerted is the length, i.e., the lay of the coiled cable. The torque required to twist the cable, i.e., angular deflection (<O), is inversely proportional to the length. Therefore, for a long length of cable it requires a considerably smaller torque load to develop the pre-twist required to compensate for the tendency to kink.

The method of laying each pretwisted coil in the figure eight configuration on top of and adjacent to the previous coil develops a compact package. The schematic of the Flake-Eight coil is shown in Figure 3.10.

A_{33} ROBOTIC DEVICE MODE

Traditional Retrieval Mechanisms (Winch & Reel)

The traditional method of retrieving the cable, other than

manual, would be to reel, or winch the cable in. For the most part, these types of mechanical devices are simple and reliable mechanisms.

The **winch mode of operation** would be to manually loop the cable over the winch drum, put a slight strain on the cable to increase the friction force (between cable & drum) and manually take up the slack as the cable was retrieved. The winch is usually stationary and **the cable is dragged along the surface of the ground.**

The **reel mode of operation** would be to fasten one end of the cable to the reel mandrel (hub) and then rotate the reel about its axis of symmetry. The device can be powered or manual. Like the winch, the reel device is usually stationary and **the cable is dragged along the surface of the ground.**

In either case, if the cable became entangled with an obstacle in its path, a high tensile load might result. In the case of the winch, the operator could allow the cable some slack to relieve the tension. In the case of the powered reel a mechanical overload clutch might be used. While the cable is protected from the potential tensile overload, retrieval is stopped until the location of the obstruction can be found and eliminated. This type device could be used with the proposed system but after the cable was retrieved, it would be coiled manually.

If the cables were contaminated as a result of deployment in an NBC area, appropriate decontamination procedures would be required prior to reeling-in and storage.

General Description Of The Semi-Autonomous Cable Retrieval Robot

An easy, quick and reliable method would be to employ a robotic type device that would both retrieve and coil the cable. The device could be computer controlled as most modern semi-automatic machines are today but with some significant differences; i.e., the memory (larger than normal) could have sufficient RAM available to utilize a powerful Artificial Intelligience-Expert System (AI-ES). Under normal circumstances, the resident ROM would handle most of the control functions. When the circumstances deviated from normal the resident controller

would be programmed to shift control to the Expert for an analysis of the circumstances before a decision to continue with the retrieval task was made.

Principal Functions Of The Cable Retrieval Robot (Figure 3.11)

The principal functions of the robotic device are to:

(1) **decontaminate the cable** if required (Figure 3.12A)

(2) **retrieve the cable** under a broad set of loosely defined circumstances (Figure 3.12B)

(3) **coil the cable** in a predefined configuration (Figure 3.12C)

(4) **package the cable,** i.e., place the coiled cable in a predefined container (figure 3.12D)

(5) **close container,** for storage or transport (Figure 3.12E).

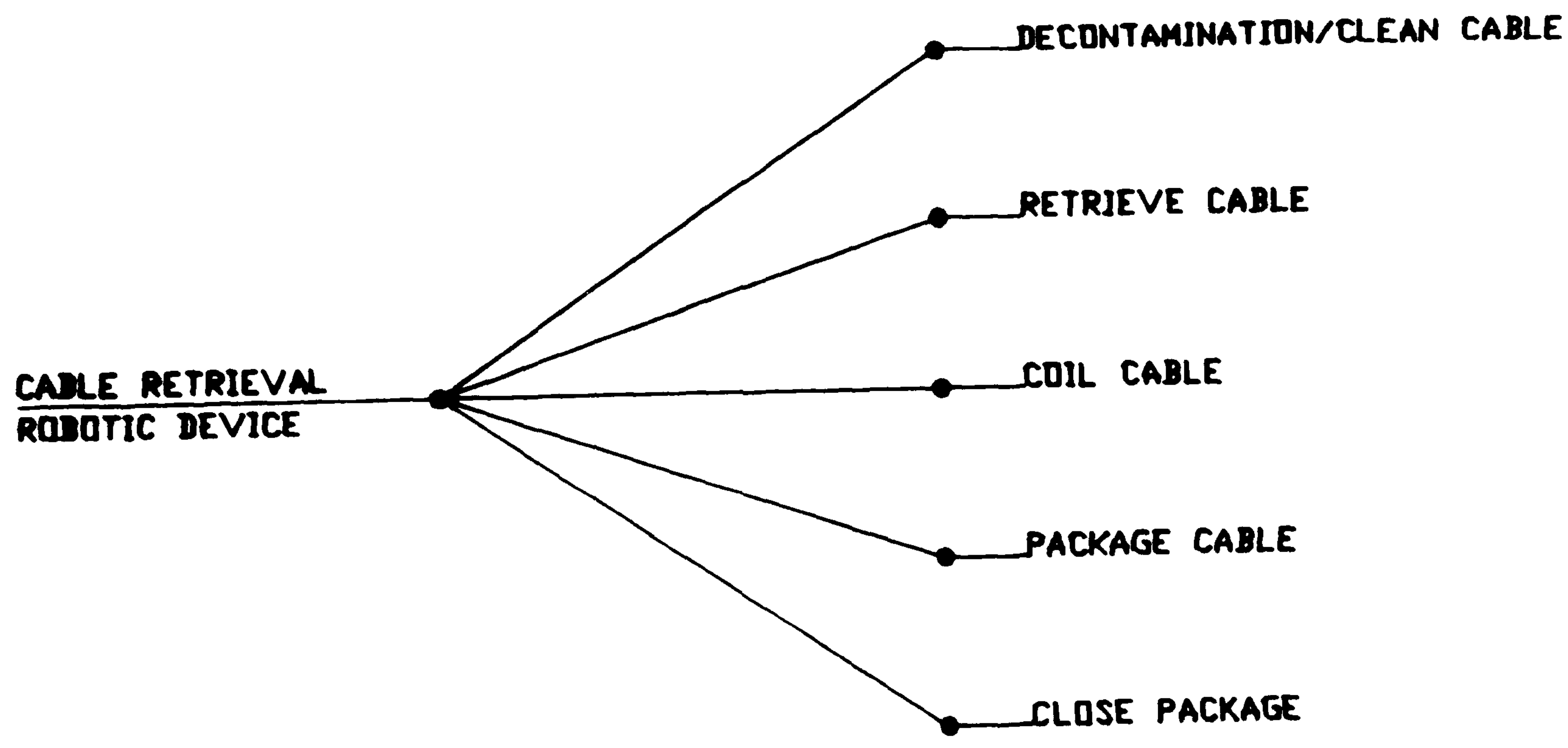
An examination of the Robotic Cable Retrieval & Coiling Device (Figure 3.13, 3.13A & B) functions suggest that #2 will be the most difficult to perform. The tactical circumstances and the terrain variations, over which the cable has been deployed, are unpredictable. However, once function #2 has been performed (or is in the process) the remaining functions are much easier to accomplish because the cable should be under the control of the robot and the remaining functions can be almost completely defined by the designer. Thus, they are more predictable.

Concept Development Methodology

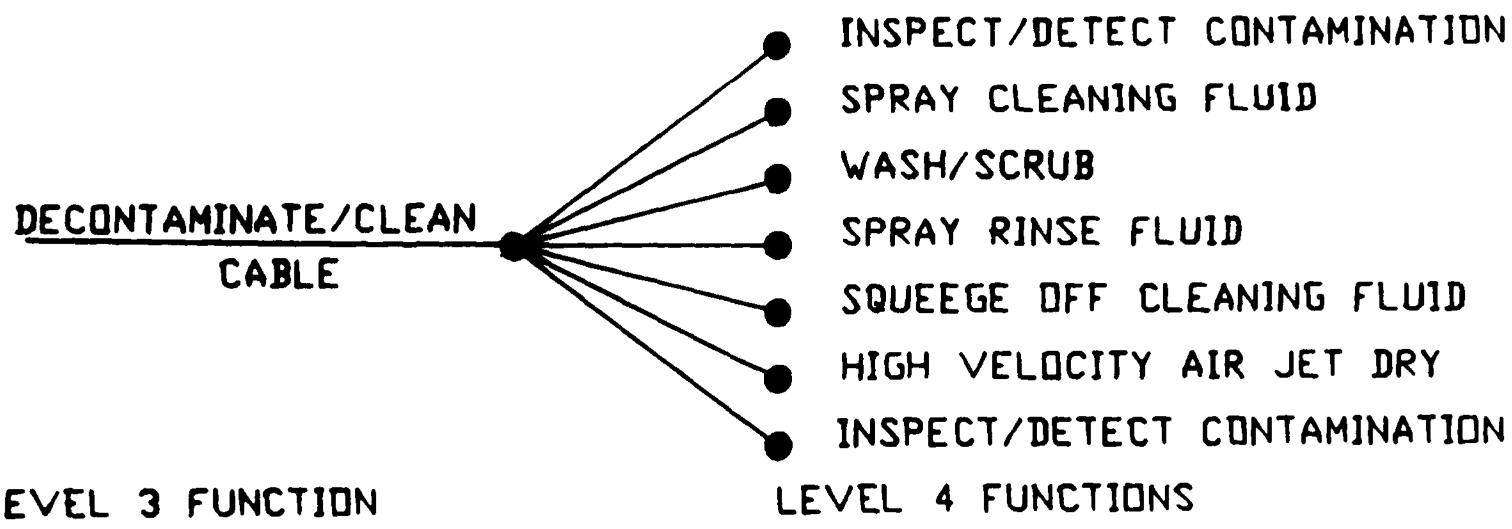
In order to develop the RCRC concept, a simplified set of hypothetical operating conditions was established to describe a realistic scenario. The basic mechanism(s) needed to retrieve the cable under these conditions were outlined. Obstacles that would prevent or seriously inhibit the retrieval function were defined and then added to the original scenario to form a more complicated one. The basic mechanism concept was then revaluated in view of the more complicated scenario and subsequently modified to deal with the new obstacles. The process was repeated a number of times until the concept as described herein was developed. Where it is relevant, some of the design logic leading to the concept is also described.

An Elementary Retrieval Scenario

In general, the designer has greater control over the deployment aspects of the system than the retrieval aspects.

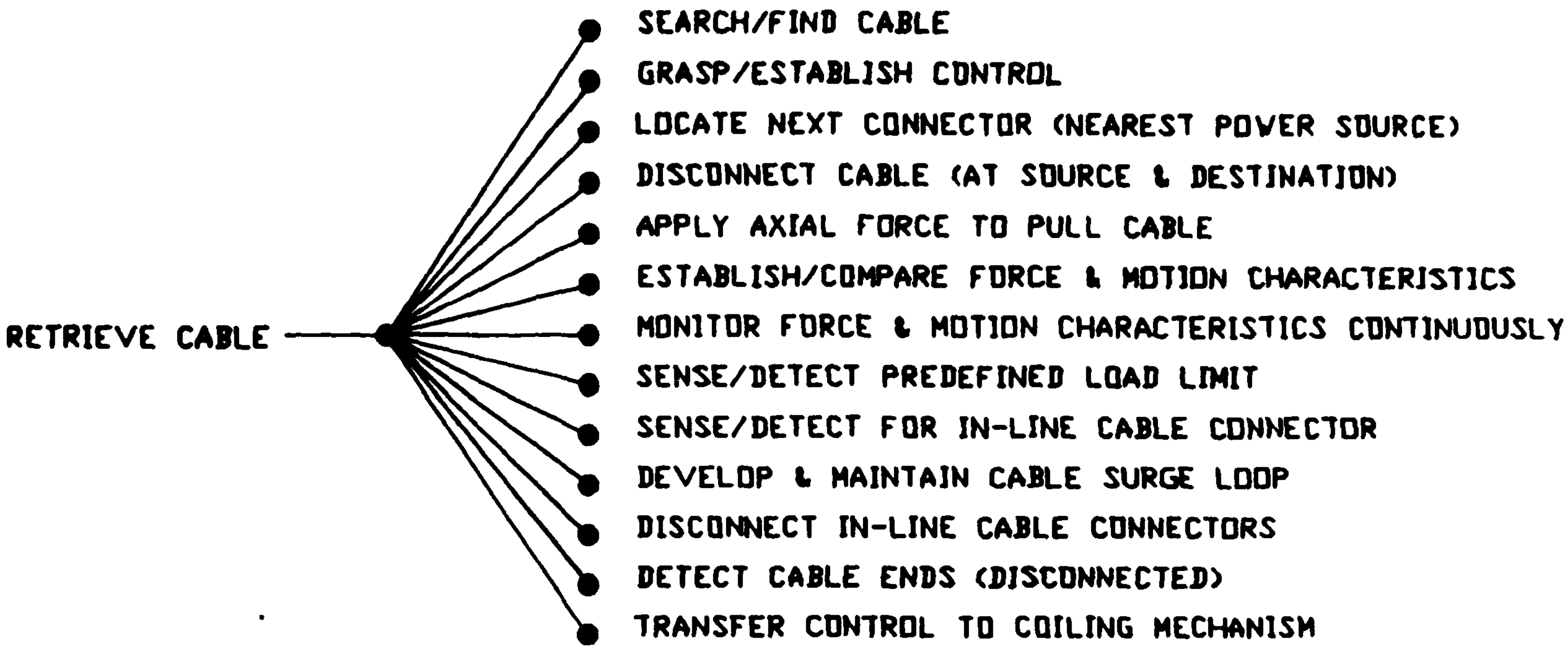


PRINCIPAL FUNCTIONS CABLE RETRIEVAL ROBOT
FIGURE 3.11



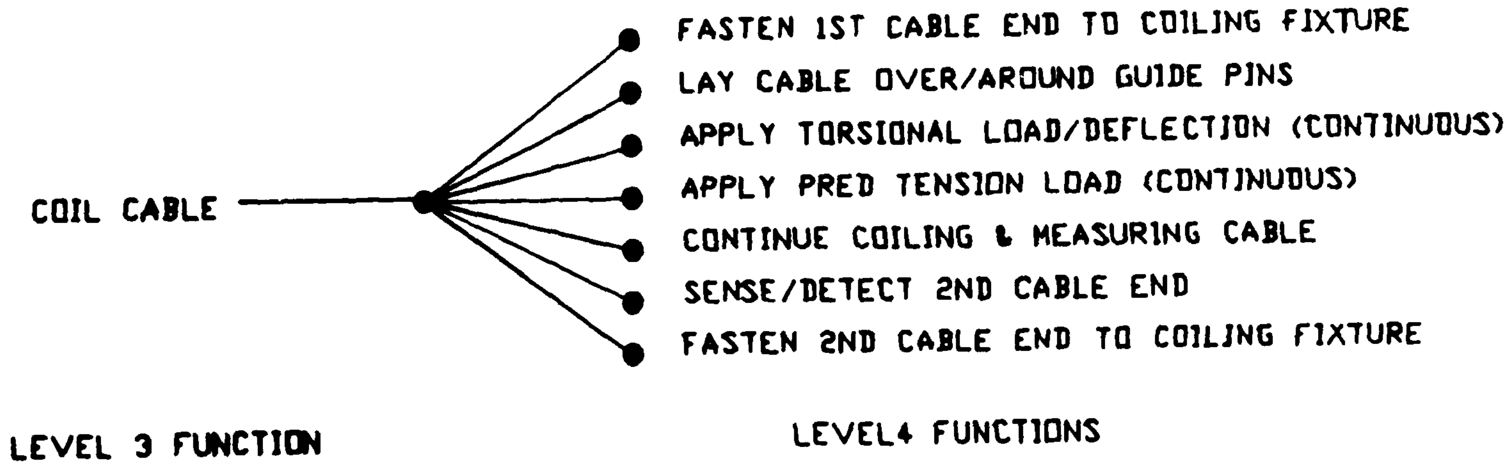
ROBOTIC
CABLE CLEANING & DECONTAMINATING FUNCTIONS

FIGURE 3.12A



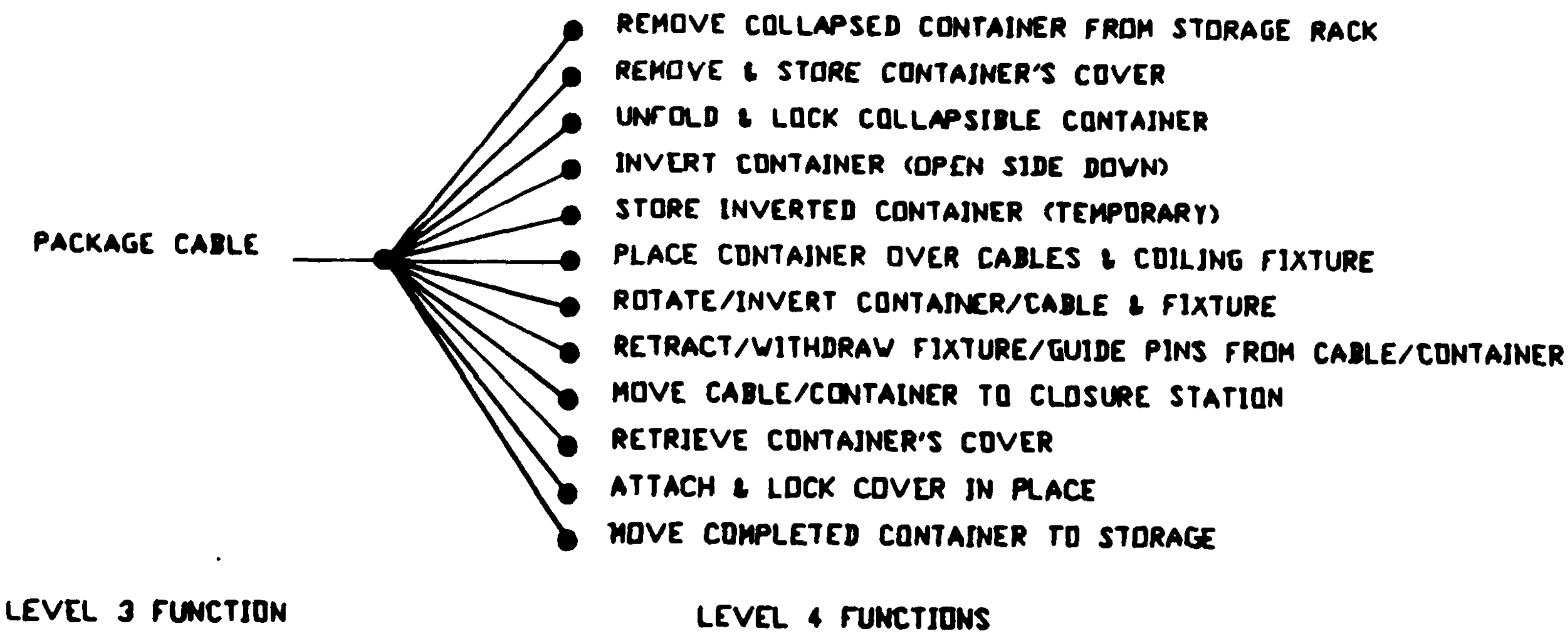
ROBOT DETAILED RETRIEVAL FUNCTIONS

FIGURE 3.12B



ROBOTIC CABLE COILING FUNCTIONS

FIGURE 3.12C



ROBOTIC CABLE PACKAGING FUNCTIONS

FIGURE 3.12D

Recognizing that this is the case, a number of scenarios that describe the field conditions/environment that might exist at the time of retrieval are considered.

One of the easier retrieval scenarios for the RCRC occurs when a single fifty foot length of cable is lying flat and almost straight on the ground with no obstacles throughout the entire length. This simplified set of conditions is sufficient to present the first major design concept decision pertaining to the degree of automation.

Interim Decision On The Level Of Automation

For example, a fully autonomous robot would receive a signal from some external source that it must retrieve a cable or cables. The robot must locate the correct cable, orient itself in the proper position for retrieval, grasp the cable and start the retrieval process. Those four simple steps (locate, orient, grasp, retrieve) imply that the robot must be a very sophisticated device. It must have enough expertise (AI) to decide where to look and when it sees (vision) a cable, it must be able to discriminate between all other cables and decide if what it sees is the correct cable (AI). It must also decide where the beginning and end of the cable are located and orient itself accordingly. Now the robot is ready to reach/grasp, and maneuver the cable into a predetermined position and prepare to retrieve.

It is important to recognized that the only essential task that has been accomplished by the robot, at this point, is to **establish control over the correct cable.**

The same task can be accomplished more easily with a little help from a friend. The cable could be manually placed in the proper position on the robot and the semi-autonomous retrieval process initiated on command from an operator (the recommended approach).

While the completely autonomous level of automation is feasible, it is very expensive and at this stage of the cable deployment/retrieval system development life-cycle is not considered to be cost effective and therefore not recommended.

Semi-Autonomous Robotic Cable Retrieval Concept (RCRC) Description

Command, Control & Communication

The fact that the system is semi-autonomous implies that an operator will interact periodically or continuously with the robot. Because the circumstances in the field are unpredictable it is considered prudent to provide the robot with an interim guide/teacher/operator. The operator will provide the initial commands and other physical support (loading the cable end) via a wireless communication link. The control will be accomplished indirectly via a remotely located computer.

Since the robot must be both rugged and mobile, it is desirable to remove as much delicate hardware as possible from the mobile unit and locate it in a more protected environment. Thus the stationary or host computer needs to communicate (wireless) with the robot's controller. The on-board controller must have a sufficient RAM memory capacity to store blocks of software transmitted by an external computer that has much greater memory capacity. The robot/controller would execute the instructions and send relevant data back to the host computer. The large shared memory capacity is necessary to support the requirements of the AI-ES. As the robot's expert system learns more about its environment it will become less dependent on operator intervention.

Physical Description & Operator/Robot Interaction (Figure 13, 13A, & 13B)

In order to initiate the retrieval process it is assumed that the operator will make the appropriate disconnect at the power panel. The cable would then be threaded into the **"Cable Gripping/Twisting Mechanism"** that is attached to the **"X-Y-Z-<0 Cable Coiling Mechanism"**. The remaining cable set-up operation could be done automatically or manually.

In either case, the cable is threaded through the device (backward) starting at the **X-Y-Z-<0 Cable Coiling Mechanism**, to the **"Surge Loop'**, to the **"Cable Tensioning & Clamping Mechanism"**, to the **"Dynamic Load Sensor Head"** and finally through the **"Cable Cleaning & Decontaminating Mechanism"** located at the input end of the device.

Under normal operations, after set-up, the operator can be

physically located some distance away from the retrieval mechanism and communicate via a "**Wireless Command Link**". Under normal circumstances the remote location might not be necessary. However, if the cable were exposed to a Nuclear, Biological or Chemical (NBC) environment prior to retrieval, the cable should be either decontaminated or abandoned. In most circumstances, the decontamination can be accomplished by thoroughly scrubbing, rinsing and drying prior to coiling and storage.

The normal control logic sequence will be imbedded in ROM and is expected to step through an interactive path similar to the following:

- o **Establish Physical Control Over Cable:** requires operator interaction, i.e., the operator inserts the cable in the appropriate position on the device and signals (GO BUTTON) when this function has been completed.
- o **Establish Logical Control:** the control circuit will examine the status of the I/O buffer & follow with a test of all the system sensors (at this point, a self diagnostic subroutine can be utilized).
- o **Develop Surge Loop & Establish/Monitor Its Physical Size:** must take place before the actual retrieval process begins because the loop provides a buffer or a surge length of cable between the Tensioning Mechanism the Coiling Mechanism. The Surge Loop helps to compensate for variations in the cable handling rate requirements of the two mechanisms (see Figure 13, 13A, & 13B). The following functions must be performed by the retrieval mechanism:

    - o Take up cable slack at **Power Panel End** (PPE) of the cable to develop the required surge loop;
    - o Logical/Sensors examine cable configuration at PPE of cable until the first Male Connector is detected;
    - o Logical/Sensors establish if cable is disconnected, also establish the logical & physical end of the cable;
    - o Logic/Sensors reexamine Surge Loop, if physical size is correct and other logical devices are satisfied then retrieval can be initiated automatically. If not, a

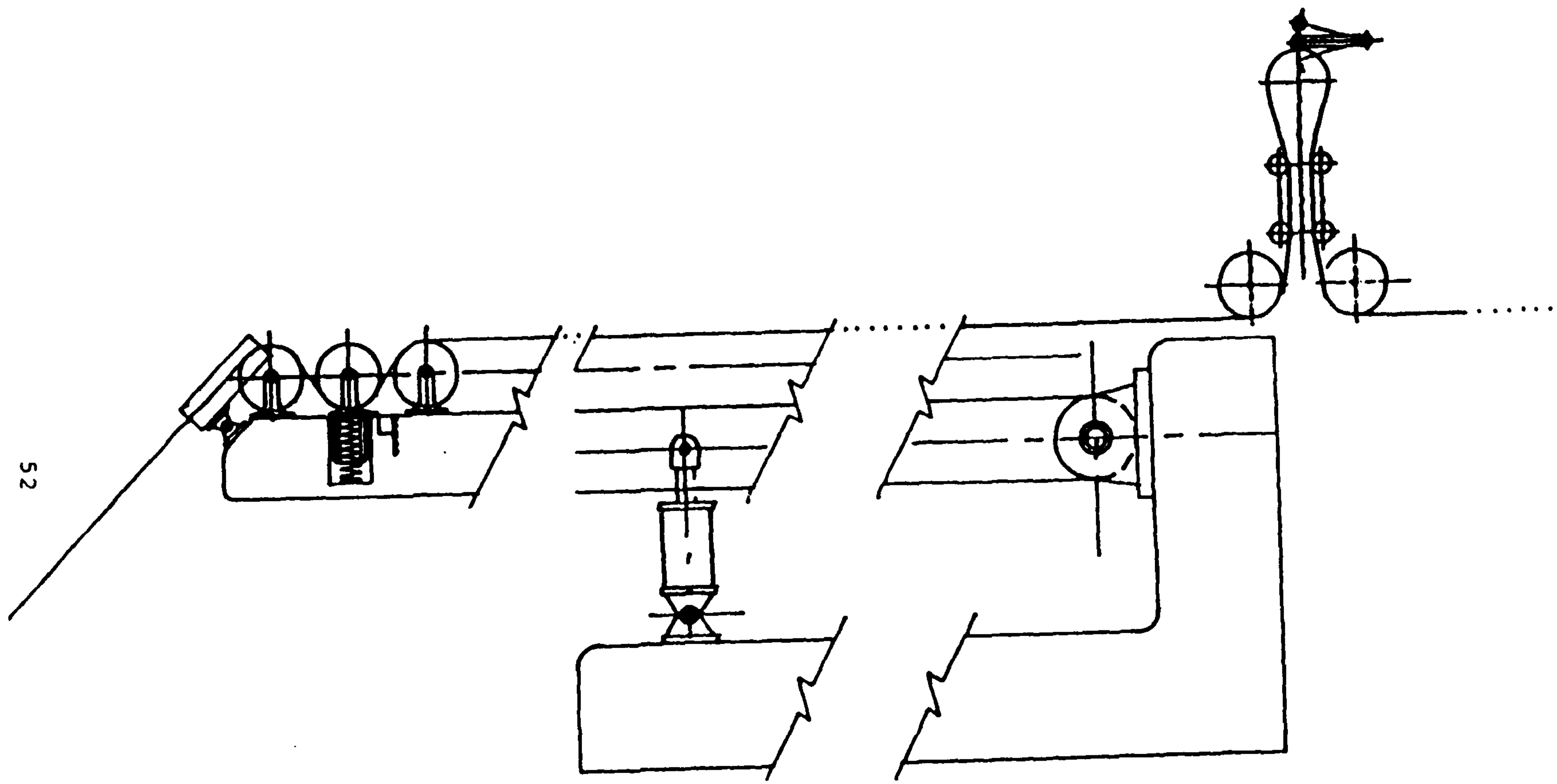
signal is transmitted back to the operator and he must initiate a logical over-ride in order to slowly retrieve the cable until the Surge Loop is fully developed;

- **Start Cable Cleaning Mechanism** as soon as the Cable Tensioning Mechanism applies the retrieval force to the cable;
- **Logical/Sensor, Cable Tension:** to continuously monitor the tensile load applied to the cable and logically compare it to the normal retrieval load range and the maximum upper load limit;
- **Logical Retrieval Decision:** if the load is normal the retrieval will continue. If not, the cable tensioner device will slowly increase the tension load until the upper limit is reached and hold at this level for a period of time before reducing the load to zero pounds. In an effort to free the cable, the procedure will be repeated a number of times. If at the end of the series of the prescribed cyclic load procedures the cable has *not* been freed, an alternate and more violent method will be initiated.
- **Cable Snapping Mode:** a violent whipping or snapping motion is applied to the cable in an attempt to free it from an unknown obstruction at an unknown distance from the retrieval device. The cable tension is reduced to zero and a prescribed amount of cable is paid out of the device in the general direction of the obstruction. The lead end of the cable (i.e., at the Cleaning End of the device) is rapidly raised and then immediately reversed a number of times to establish a traveling wave (vibration) in the cable. While this violent procedure is expected to free the cable, there will be occasions when it will fail. The amplitude and frequency of the standing wave will be monitored and compared to the input. The reflected wave might be utilized to indicate the distance from the robot to the obstruction. However, the traveling wave might be so heavily damped that there is no measurable reflected wave. Another related approach is to apply the maximum tensile load to the cable and then send a tensile/compression wave down the cable similar to plucking

(exciting) a banjo string. In any case, it appears reasonable that the approximate distance to the obstruction can be established. The commander can decide, based on actual conditions in the field, whether the cable should be manually freed or the retrieval process should be aborted. Assuming that the cable has been freed, the retrieval process can continue.

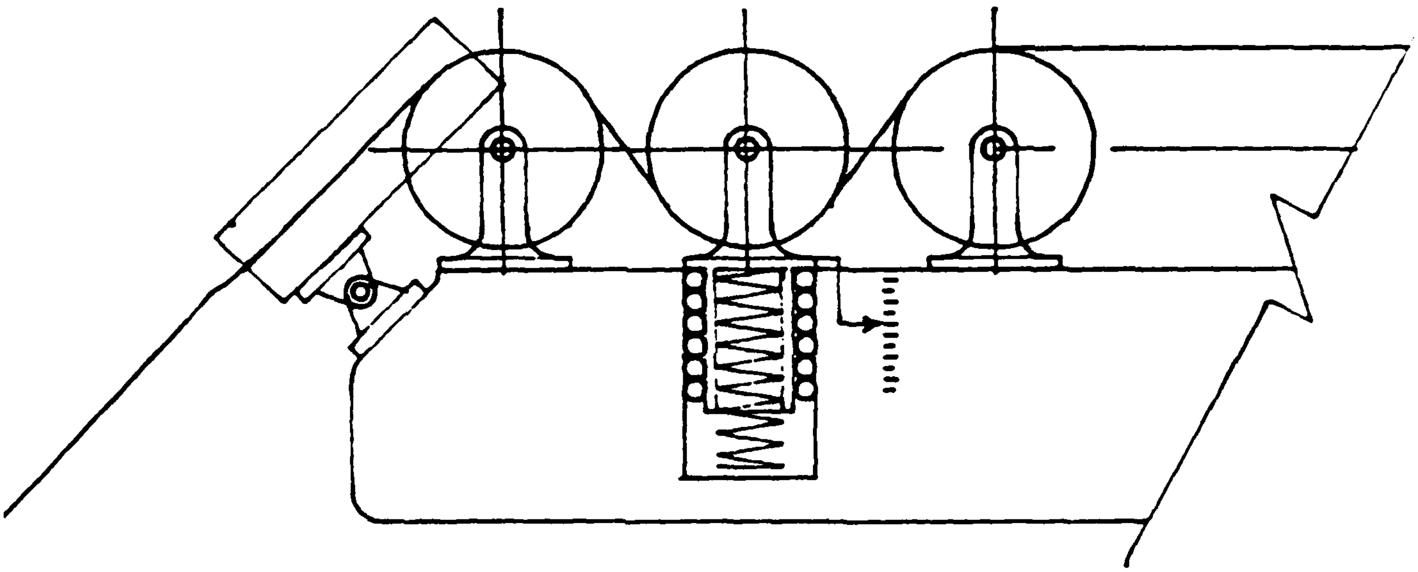
- **Physically Clamp PPE Connector To Coiling Fixtrue:** this function is performed by the cable coiling mechanism and requires that the Connector's Male Prongs be pointing toward the ground.
- **Physically Coil Cable** by applying both a tension and torsion load to the cable as it is stretched between the Connector Clamp and the **Loop Post.** When the X-Y motion of the Gripper completes the first lay of the coil, the cable is looped around the Loop Post and the direction of the X-Y mechanism and cable is reversed. The cable is now stretched and twisted between the first and second Loop Post. The process is continued until the Logical/Sensor monitoring the retrieved length of cable determines that one fifty foot length of cable has been retrieved and partially coiled.
- **Physically Disconnect Two Cables**: the disconnect procedure will be dependent on the design of the connector. A mechanism to perform this function should be a straightforward mechanical design project. The coiling mechanism must stop temporarily while the disconnect and the clamping (both male and female connectors) takes place at the coiling fixture.
- **Insert Collapsible Container Over Coiled Cables:** the container must be inverted, i.e., open side facing toward the ground, and placed over the coiled fifty foot length of cable. When this step is completed both the male and female connector clamps will release. The coiled cable and container are now pushed upward and away from the Loop Posts. The assembled package of clean pre-twisted cable, with both male and female connector exposed and ready for reuse, is now ready to be covered and stored.

The design requirements and trade-offs that must be made to establish the preliminary robot design demands the implementation of the NSIA trade-off technique (or some similar procedure) in Phase II. The robotic retrieval device concept described above will be based on several well defined assumptions that are subject to review and approval by MERADCOM.



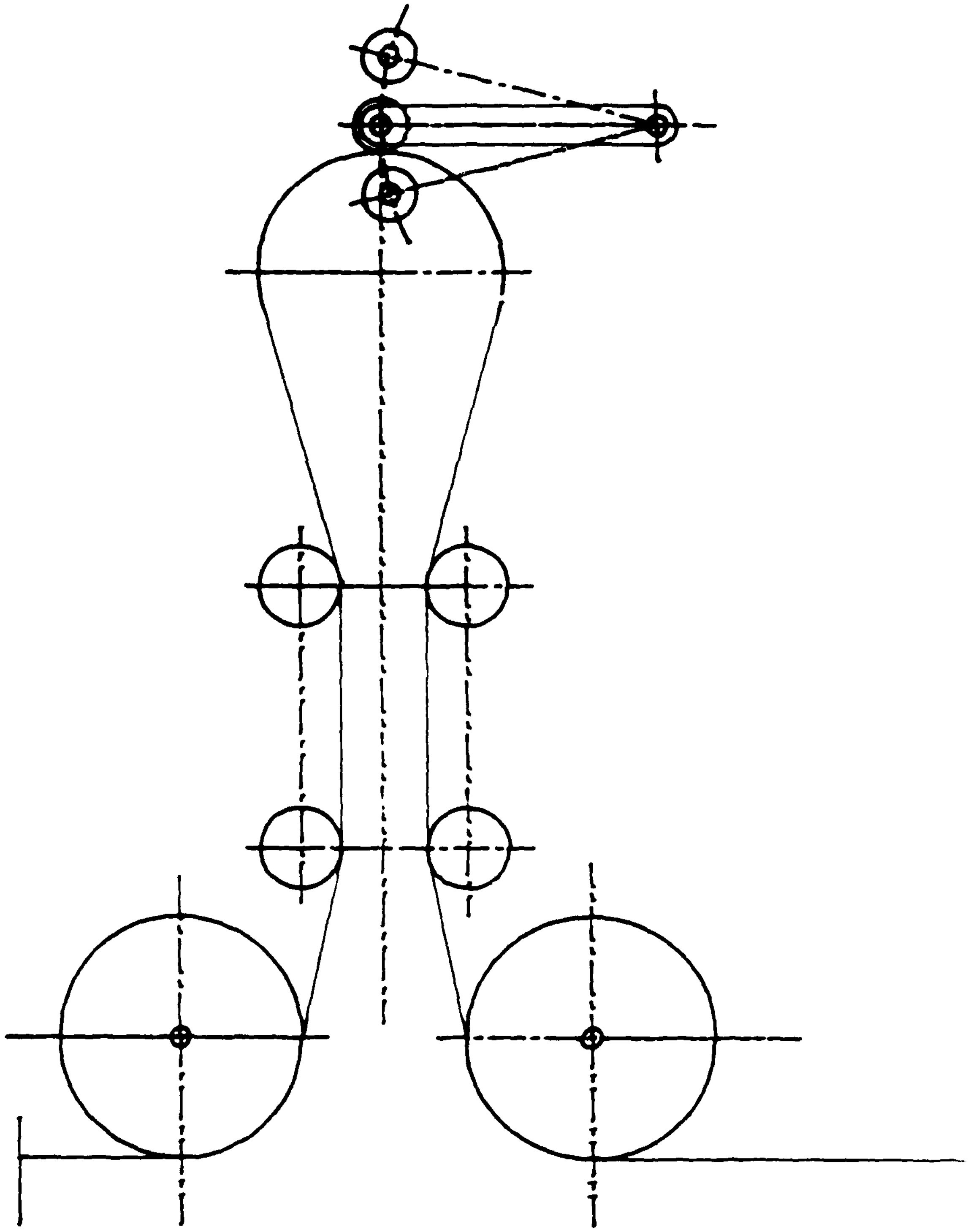
SCHEMATIC:
ROBOT RETRIEVAL DEVICE

FIGURE 3.13



SCHEMATIC:
CABLE LOAD SENSING

FIGURE 3.13A



SCHEMATIC:
CABLE SURGE LOOP

FIGURE 3.13B

4.0

TASK III
CONCLUSIONS & RECOMMENDATIONS

4.1 GENERAL CONCLUSIONS REGARDING THE FEASIBILITY OF THE CONCEPT

The central conclusion of the Phase I study is that the original deployment (RDEC) and retrieval (RCR) concept (Figure 4.1 & 4.2), with minor modifications, is feasible. The deployment schematic shown in Figure 4.3 indicates some of the obstacles that can be overcome by this approach. In addition, there are multiple mechanism design approach options and deployment method options available to Ft. Belvoir that will enhance the opportunity to optimize the prototype rapid deployment/retrieval system design and demonstration.

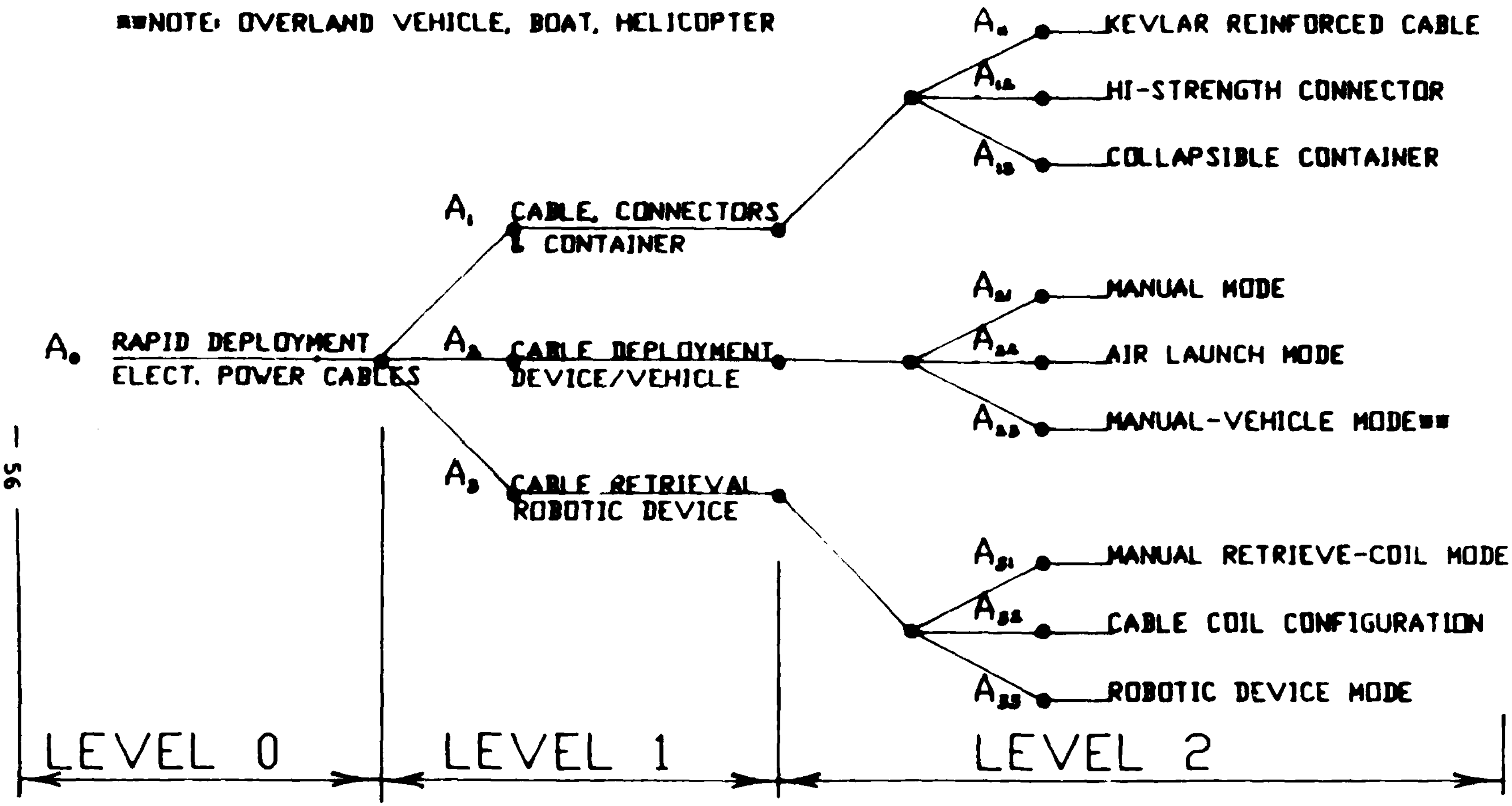
As previously noted, the detailed RDEC/RCR system concept, as described in the Phase I proposal and in Section 3.0 of this report, employs some nine functional components (Figure 4.1). Thus, the concept feasibility and development risks are dependent on estimates that include a composite picture of all nine components performing as predicted. In addition, several of the more important system components are supported by both a primary and at least one alternate (back-up) concept. Therefore, based on the primary conceptual components only, **the development risks are estimated to be low to moderate.**

The detailed information and technical data required to support that conclusion are documented and reviewed in Section 3.0, Analysis & Findings and Appendix A, A Computer Model of the Cable Air Launch Component.

A review of the conclusions pertaining to the higher priority Level 2 Functional Components and the Phase II Development Program Implementaion Recommendations follows.

PHASE II DEVELOPMENT PROGRAM, IMPLEMENTATION RECOMMENDATIONS

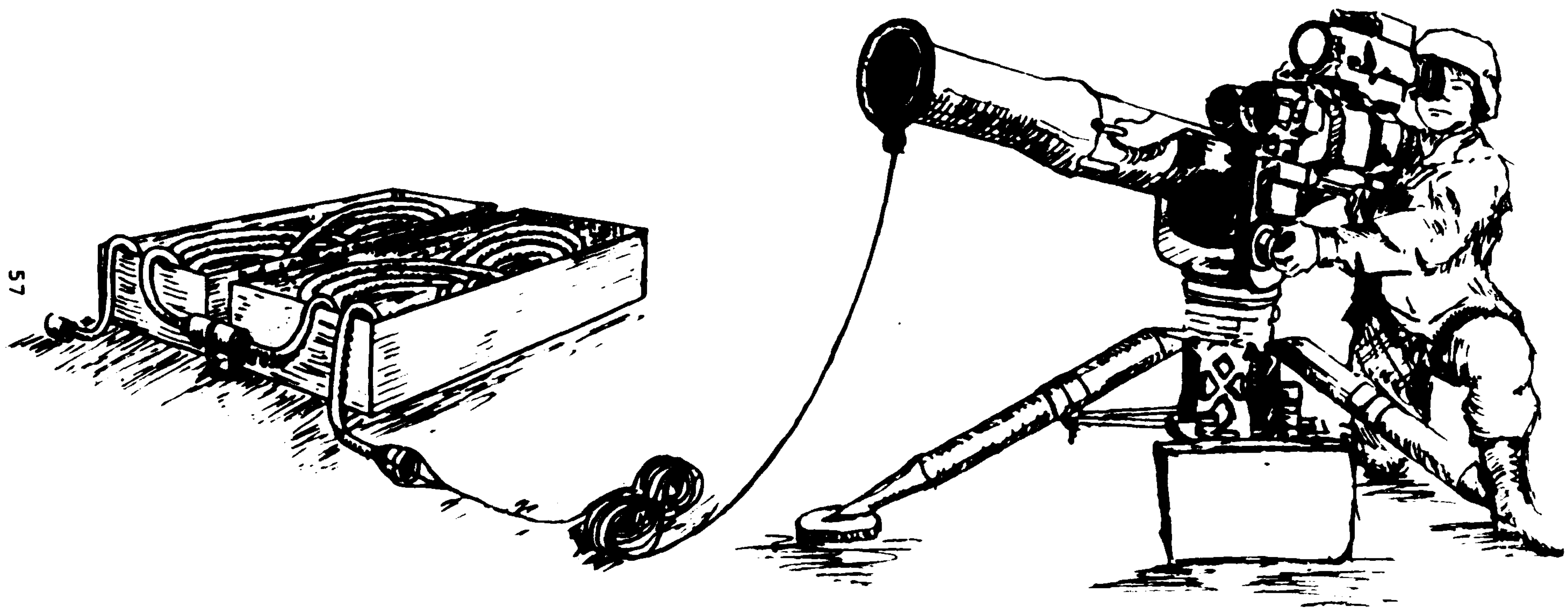
The design and development of both the RDEC & RCR system components results in a significant size R&D program. Figure 4.1



RDEC FUNCTIONAL COMPONENTS GROUPING HIERARCHY

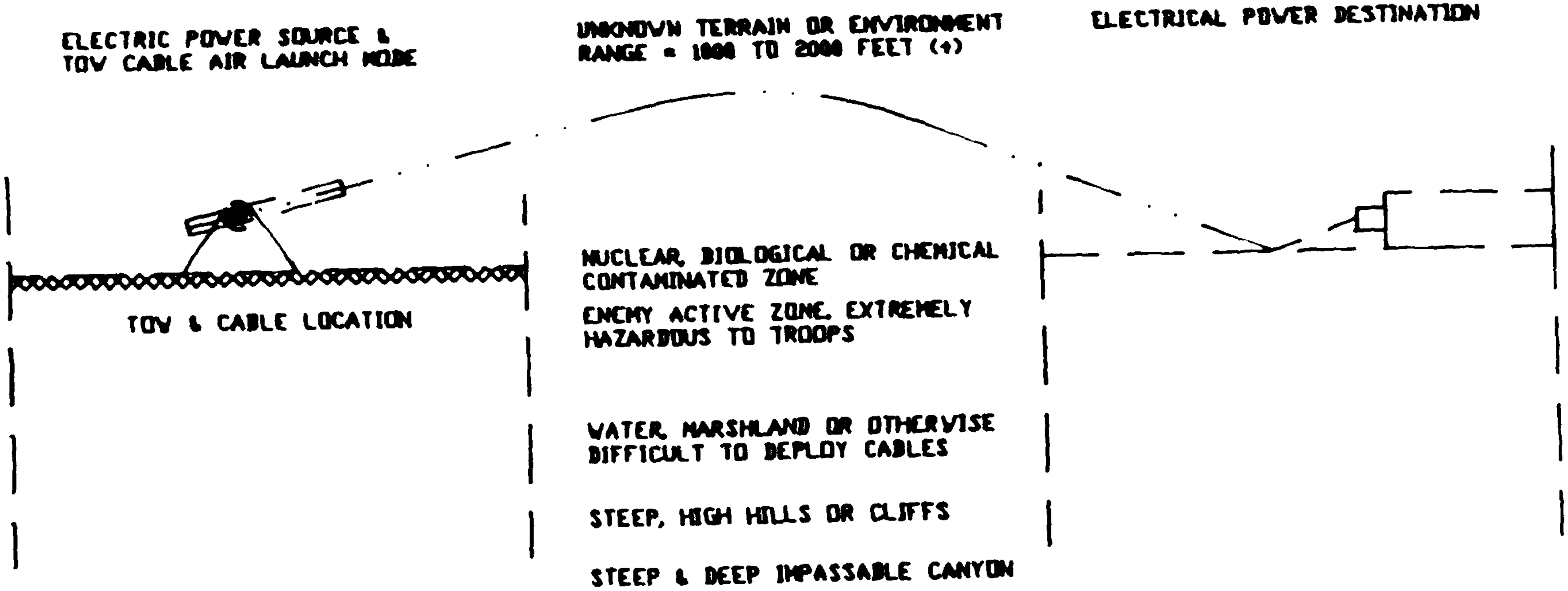
FIGURE 4.1

UNIVERSITY RESEARCH ENGINEERS
AND ASSOCIATES, INC.
HERCULES, CA 94547
DESIGNER: TOM CALLAHAN
APPROVAL: Tom Callahan
S-DATE: / / C-DATE: / /
DWG TITLE: FUNCTIONAL COMPONENTS
PROJ. SYMBOL RDEC-01



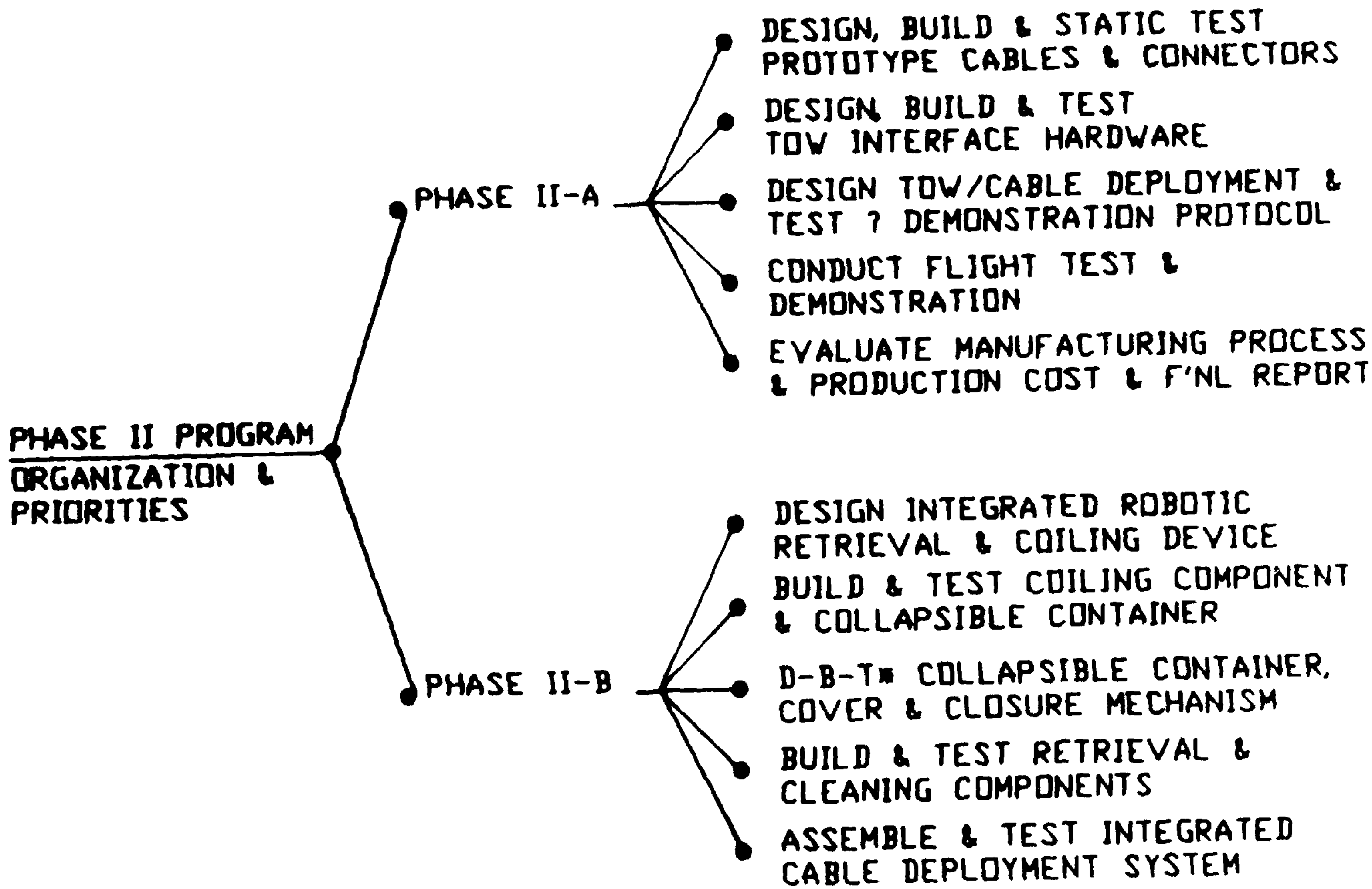
TOW MISSILE CABLE AIR LAUNCH
SKETCH

FIGURE 4.2



AIR LAUNCH: OBSTACLE
NEUTRALIZATION

FIGURE 4.3



PHASE II: PROGRAM IMPLEMENTATION &
MANAGEMENT CONTROL STRATEGY

FIGURE 4.4

shows three Level-1 components; i.e., A_1 Cables, Connector & Container; A_2 Cable Deployment Device/Vehicle and A_3 Cable Retrieval Robotic Device. The general concensus both at Fort Belvoir and UREA is that the cables, the connectors and the deployment (RDEC) component have a much higher implementation & demonstration priority than either the container or the retrieval (RCR) component. It is also true that the RCR component design activity would normally be scheduled after the completion of many of the RDEC components.

The Phase II Design, Development and Demonstration Program has been organized to reflect both the development priorities and the logical developmental effort as noted above. The hierarchal format or tree structure that reflects the proposed Phase II program implementation and control strategy is shown in Figure 4.4.

In addition, it should be noted that the design of the A_3 robotic component would include a complicated mechanical device, a special purpose computer (requires intensive hardware & software development), dedicated sensors, and a telecommunication device. Thus, it is clear that the lower priority level-1 system component is also the most expensive element of the total development effort.

The **Phase II Implementation Recommendations** are:

1.0 **Implement the the Phase II-A Program** as outlined in Figure ES-4

2.0 **Evaluate the Phase II-A Demonstration** and the potential long range benefits of this power cable deployment method as well as its logistics burden . . . if the results warrant;

3.0 **Implement the Phase II-B Program** as outlined in Figure 4.4.

CONCLUSIONS: COMPONENT A_{11}
#6AWG-4C CABLE WITH KEVLAR BRAID REINFORCEMENT

The investigation shows that the subject cable can safely withstand the launch loads (tension or torsion) applied by the TOW missile acceleration. It is clear that this can be accomplished with an adequate margin of safety, i.e., a factor of safety of five or more can be achieved without significant increase in the

cable weight. It is recommended, therefore, that this component be considered acceptable unless the Phase II investigation indicates that an alternative with more attractive functional attributes is available.

The general conclusions reached at this stage of the investigations are:

(1) the braided Kevlar reinforcement for the TOW Air Launch Concept is feasible using SOA cable design and manufacturing technology

(2) while the Kevlar would provide both increased strength and useful life when subjected to normal field abuse (crushing loads from vehicles, etc.), no definitive quantities could be established

(3) while the cause of cable failures (crushing) appear to be well established, the failure mechanism and/or mode is not well defined

(4) if the failure mode were more precisely characterized, it appears to be within the SOA of cable design & manufacturing to improve that performance attribute

(5) the cable failure mode should be investigated more thoroughly as a specific task in Phase II

(6) the potential for a flat cable developing a stable on-edge configuration during or after deployment is too great to risk recommending its use as a prototype

(7) **the innovative cable design to improve its ability to resist damage in the field will complement the attributes required for air launch** (Figure 3.4)

(8) an experimental cable & connector should be designed and manufactured as a single integrated entity (see A_{12} HI-STRENGTH CONNECTOR)

(9) the cable design, as concieved during the Phase I study, will require modifications to the traditional manufacturing process (see Innovative Cable/Connector Design Concept)

(10) **commercially available power cables are neither designed** nor **constructed to a quality level compatible with the SOA potential.**

CONCLUSIONS: COMPONENT A_{12}
HIGH STRENGTH CONNECTOR

A high strength connector design tailored specifically for the requirements of this program; i.e., Kevlar reinforced cable, tension load of an air launch, etc. , is feasible. In addition, there are several commercial connector designs that will satisfy the requirements of the air launch & robotic retrieval application. There is an excellent opportunity to optimize an integrated cable-connector concept that will satisfy several performance attributes considered to be important by MERADCOM.

CONCLUSIONS: COMPONENT A_{13}
COLLAPSIBLE CONTAINER

A Collapsible Container for use as a shipping and storage package for fifty feet of cable (or more) is technically feasible. The conclusion is based on the design schematic (Figure 3.8) and a small working model. A full scale prototype should designed and built as a part of the Phase II-B Program.

CONCLUSION: COMPONENT A_{22} CABLE DEPLOYMENT, AIR LAUNCH MODE

The flexible/rapid cable deployment methodology, as emphasized is in the proposal; i.e., a Primary Air Launch Cable Deployment Device backed up by several alternative deployment methods, is feasible. The TOW missile system has the operational attributes that are compatible with the conceptual design requirements. The research, computer model analysis, and discussions with the TOW System Program Office support that conclusion. The discussions with TOW/SPO not only supported the feasibility of the concept but they contributed helpful design suggestions.

Their are a number of devices in the DOD inventory that could be used in this application but the TOW missile appears to be the optimum. The other devices can either be applied directly to the application or used as a reference model for a back-up design.

CONCLUSION: COMPONENT A_{32} "FLAKE-EIGHT COIL CONFIGURATION

The flake-eight coil configuration is an ideal approach to satisfy the needs of this application. If the length of the "lay" (48" dimension, Figure 3.10) is large compared to the bending diameter of the coil (9" for a #6AWG-4c cable), the compensating counter twist requirements needed to eliminate kinks is mimimized.

CONCLUSION: COMPONENT A_{33} CABLE RETRIEVAL, ROBOTIC DEVICE

While a robotic type mechanism, autonomous or semi-autonomous, to retrieve and coil the cable is a design challenge it is technically feasible.

There is a very high confidence level that a Phase II-B demonstration of this component would be successful.

RECOMMENDATION: The Ad Hoc Subgroup on Artificial Intelligence & Robotics of the Army Science Board suggested(1) that the initial design & development of a robot should incorporate teleoperated controls and by implementing a program of **"Preplanned Product Improvements"** (P^3I) the integration of Artificial Intelligence, Expert System (AI/ES) technology can take place smoothly at a future date. This approach is particularly appropriate in this instance since there is no retrieval experience related to this concept to provide a basis for the "Expert Knowledge" requirements of the software. Thus, it is recommended that the Army Science Board's teleoperated robot design approach should be adopted in Phase II-B.

UREA considers that a semi-autonomous (teleoperated) robotic device to retrieve & coil power cable is more practical and represents the least development risk and a cost effective approach to MERADCOM.

APPENDIX A

COMPUTER MODEL

RAPID DEPLOYMENT OF ELECTRIC POWER CABLES (RDEC)

A_{22} AIR LAUNCH MODE

INTRODUCTION

The central thesis of the RDEC concept is the capability to air launch one end of a power cable (#6AWG-4c) from the power source and deliver it to a power user at some remote tactical location(s). The primary objective of this effort is to develop a generalized computer model of the cable trajectory in order to establish and understand the critical design parameters (Table A-1).

TABLE A-1

CRITICAL DESIGN PARAMETERS

- AIR DEPLOYMENT: THRUST REQUIREMENTS OF THE PROPULSION (DELIVERY DEVICE) SYSTEM; i.e., SINGLE APPLICATION OF MOMENTUM (MORTAR) OR CONTINUOUS APPLICATION OF MOMENTUM (MISSILE)

- AERODYNAMIC DRAG OF THE CABLE ON THE DELIVERY DEVICE

- IMPACT OF EXTERNAL FORCES (CABLE WEIGHT & MASS INERTIA) ON THE STABILITY & PERFORMANCE OF THE HOST DELIVERY DEVICE

- TENSION & SHOCK LOADS APPLIED TO THE CABLES AND CONNECTORS

A basic data element need of this analysis was to obtain reasonable estimates of the airborne loads in order to establish

the approximate thrust requirements of the propulsions system. With the thrust established, it was then possible to (a) examine the fundamental propulsion methods; e.g., single impulse (mortar or cannon) or continuous momentum device (missile), (b) decide which method was more suitable for this application, (c) provide the fundamental data needed to help guide the search of the current DOD weapons inventory and establish candidate launch system(s) for further evaluation, (d) substitute the dynamic specifications (velocity, mass, launch angle, etc.) of the candidate delivery vehicles into the computer model to establish which vehicle(s) satisfied the conceptual performance requirements of the proposed RDEC system. Another important aspect of the computer model is the ability to examine "What If" type scenarios very rapidly and establish the sensitivity of the system. Thus, the critical system parameters can be studied to establish their synergistic relationships.

TABLE A-2

COMPUTER MODEL PARAMETERS & SYMBOLS

THRUST (OF PROPULSION SYSTEM)	F
CABLE TENSION	T
INSTANTANEOUS TRAJECTORY ANGLE	0
CABLE ATTACHMENT ANGLE	O
LIFT COEFFICIENT	C_L
DRAG COEFFICIENT	C_D

TECHNICAL DISCUSSION

The initial effort centered on the development of an analytical model of a thrusted cable carrier vehicle. A two dimensional mathematical representation of the model was developed and is described in detail in Figure A-1, Titled: **BASIC RDEC AIR LAUNCH MATHEMATICAL/COMPUTER MODEL.**

The model set-up of the cable-vehicle system is based on classical force-balance (on a point in space) type

problem. The forces included in the analysis are:

- o the thrusting force (assumed to be constant for the duration of the flight),
- o the weight of the vehicle (assumed to be constant for the duration of the flight; i.e., the actual reduction in vehicle mass caused by the fuel depletion is neglected),
- o the tension force(s) developed in the cable
- o the lift & drag force on the vehicle (based on assumed lift (C_L) and drag (C_D) coefficients).

The acceleration of the deployed cable was also modeled as a point mass that accelerates at one half that of the vehicle. This relationship reflects the fact that the center of mass of the cable always lags the vehicle position by a factor of two.

The cable tension and length are based on a parabolic profile which, in turn, reflects freely supported end conditions.

The mathematical model of the force balance results in four simultaneous ordinary differential equations. The equations are then solved numerically on the computer by using a forth order RUNGE-KUTTA algorithm.

TABLE A-3
INITIAL CONDITIONS
(i.e., @ TIME IN SECONDS=0)

INITIAL VELOCITY (V_o, Meters/Second)	0
TRAJECTORY ANGLE (LAUNCH ANGLE, degrees)	30^o
TOW MISSILE MASS Kilograms (37 lb.)	17Kg
THRUST, Newtons, N (219 lb.)	2750 N
CABLE MASS DENSITY Kg/M (meter), (0.67 lb/ft). .	1.0
FRONTAL AREA/MISSILE	$0.1M^2$
C_D	0.5
C_L	0.2

The six illustrative cases are summarized in Figure A-2. The first case illustrates the basic TOW cable deployment concept using published TOW parameters. Four additional cases were examined where the thrust is varied by plus or minus 10% and the launch angle is varied by plus or minus 5° (i.e., a 2X2 matrix). The four additional cases demonstrate how sensitive the system is to both thrust and launch angle.

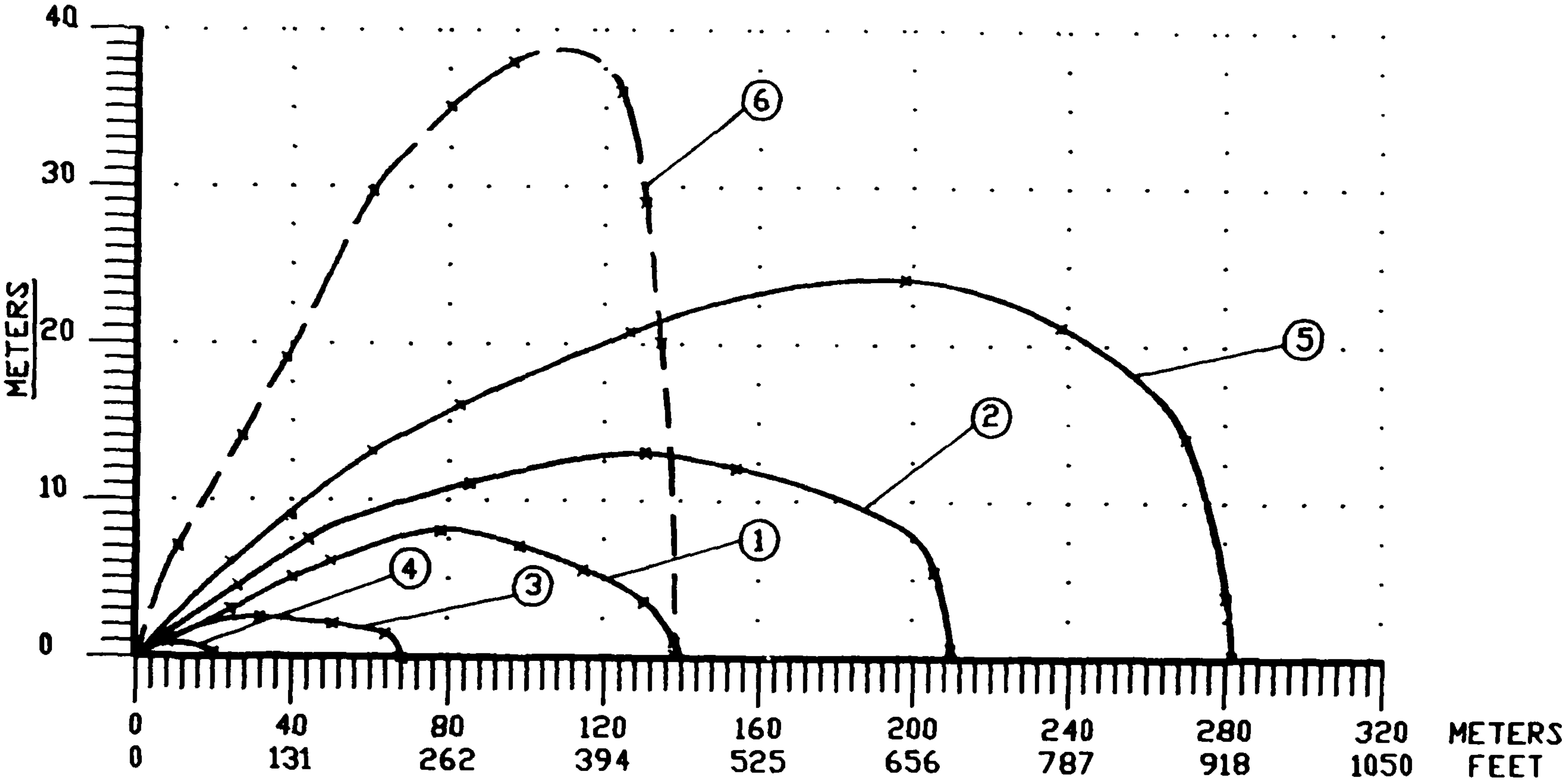
The sixth case attempts to demonstrate the limitations of the single impulse case. The initial velocity (V_o) of 75 M/Sec. applied to the cable corresponds to the maximum TOW missile velocity and does not represent the actual muzzle velocity of any known artillery or mortar weapon.

TABLE A-4

ANALYSIS OF SIX BASIC AIR LAUNCH CASES

INITIAL CONDITIONS AND RESULTS

CASE NO.	THRUST FORCE (N)	INITIAL ANGLE (0°)	INITIAL VELOCITY M/S(Ft/S)	TIME OF FLIGHT Sec.	RANGE M(Ft)	COMMENT
1	2750	30	0(0)	1.8	129 (423)	BASE CASE
2	3000	30	0(0)	2.6	210(689)	Nx(1.1)
3	2500	30	0(0)	1.2	64 (210)	Nx(0.9)
4	2750	25	0(0)	0.7	21 (70)	$30^{\circ}-5^{\circ}$
5	2750	35	0(0)	3.4	218(921)	$30^{\circ}+5^{\circ}$
6	0	30	75(245)	3.6	131(430)	MORTAR



CABLE AIR LAUNCH TRAJECTORIES
(BASIC CASES, PAGE A-5)

FIGURE A-1

basis for judging the desirability of adopting the alternatives that have been so analyzed.

The NSIA trade-off technique produces positive or negative numerical values for the effects of a particular parameter or other characteristics and features of a system. As such, it represents an evaluation of the system from one particular point of interest. The evaluator uses numerical values from +1 to +100 for estimated favorable effects and values from -1 to -100 for those found to be unfavorable. An estimate of either +100 or -100 would override all other considerations.

Several precautions should be taken in applying this technique. Evaluation should be made only by individuals fully qualified in the area of the system characteristics being studied. Second, whenever possible, a given evaluation should be made independently by two or more such experts, with the average of all to be used.

Finally, all possible effects of a given alternative should be considered. When this has been done for all the alternatives that have been proposed, a clear and conclusive indication is obtained of the degree of desirability of each. It is evident that every effort must be made to describe clearly and completely any alternative that is proposed so that all the evaluators obtain a uniform and accurate understanding of that alternative.

PROCEDURES FOR APPLYING THE NSIA TECHNIQUE:

(1) Define the problem to be solved clearly and concisely.

(2) List all the alternatives that can be considered as possible solutions to this problem.

(3) For each such alternative, obtain or prepare drawing, schematics, and other materials that define it clearly.

(4) For each alternative, prepare a data sheet similar to the one shown as Figure 1.

(5) Determine all of the parameters, such as reliability, safety, cost, and schedule, that could be affected if this alternative were adopted. Enter these by number in the appropriate column of the data sheet for this alternative. Enter special information of significance about any of these characteristics in the column headed "Considerations".

(6) For each characteristic entered in the "Parameters" column, establish and enter in the "Relative Weighting" column a suitable weighting value that represents the relative importance of each characteristic to the system. A value of unity should be assigned to the least important characteristics, with appropriate whole number values given the others, according to their importance. For example, if the effect on schedule were considered least important, it would be given the factor of 1, and if safety were considered to be twice as important, it would be weighted by a factor of 2. In some cases, fractional weighting values can be used.

(7) Evaluation of each alternative in relation to each system characteristic or other parameter should then be made by the individual or group best qualified to judge its desirability. For example, the reliability group would evaluate the feature from the viewpoint of its impact on a subassembly or system reliability; the human factors group would do the same from the human engineering viewpoint. Whenever possible, a number of independent evaluations should be made. In every instance, however, utmost care must be taken that each characteristic associated with an alternative is evaluated in isolation, never as influenced by other characteristics. Each evaluator, having made his evaluation, assigns to his findings an appropriate positive or negative number to indicate the degree of desirability or undesirability that has been determined.

(See the scale of numerical values given in Figure 2.1). If several evaluations have been made of the alternative in relation to a single system characteristic, the average of the group is computed and entered, as either undesirable or desirable, in the "Basic Rating" column.

+100	NECESSARY	-10	
+90		-20	
+80		-30	UNDESIRABLE
+70	VERY DESIRABLE	-40	
+60		-50	
+50		-60	
+40		-70	VERY UNDESIRABLE
+30	DESIRABLE	-80	
+20		-90	
+10		-100	UNACCEPTABLE
..0..	NO EFFECT	...	

BASIC RATING SCALE
NSIA TRADE-OFF METHOD

FIGURE 2.1

(8) Multiply the assigned value in the "Basic Rating Value" (see Fig. 2) by its corresponding weighting factor, and enter the product, as either undesirable or desirable, in the "Adjusted Values" column.

(9) Having done this for each of the system characteristics or other parameters selected as significant for this alternative, add algebraically all the values entered in the "Adjusted Values" column, establishing thereby a total net value for the alternative.

(10) Obtain a total weighting factor for this design feature by adding all weighting values entered on the data sheet.

(11) To determine an average net value for the design features, divide the total net value by the total weighting factor. The resulting algebraic sign (plus or minus) will indicate whether this alternative is desirable or undesirable, and its absolute value will measure the degree of its importance. The average net value thus determined is the figure of merit for this particular alternative.

When this technique has been <u>objectively</u> applied to all the alternatives under consideration, the average net value determined, for each, will provide a guide to an optimum solution to this problem.

APPENDIX C

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APPENDIX D

A86-98:
NOVEL CONCEPTS FOR RAPIDLY DEPLOYABLE
ELECTRIC POWER DISTRIBUTION SYSTEMS

CATEGORY: Exploratory Development

DESCRIPTION: Electric power usage in the field Army today continues to rise with the increased use of sophisticated weapons systems and equipment. This trend, coupled with decisions aimed at reducing total numbers of generator sets in the field, has resulted in increased interest in the distribution of electric power. In particular, consolidation of multiple loads of greater and lesser criticality and multiple sources (some in standby) on the same cable-type distribution system appear a viable approach even for some tactical units. The high degree of mobility envisioned as essential on the modern battlefield mandates that these cable-type electric power distribution systems be rapidly deployable and redeployable. The objective of this work is to develop and evaluate new concepts for electric power distribution under field conditions which will yield rapid deployment /redeployment and high mobility. Specifically, connector systems are found to be a major problem area in that they are usually somewhat fragile and susceptible to environmental degradation and to be both slow to engage/disengage and cumbersome to handle. New ideas are needed which will provide for low loss, multiple conductors, resistance to environmental effects and rapid fault resistant connection/disconnection. Other novel approaches in the area of cable-type electric power distribution systems are encouraged.